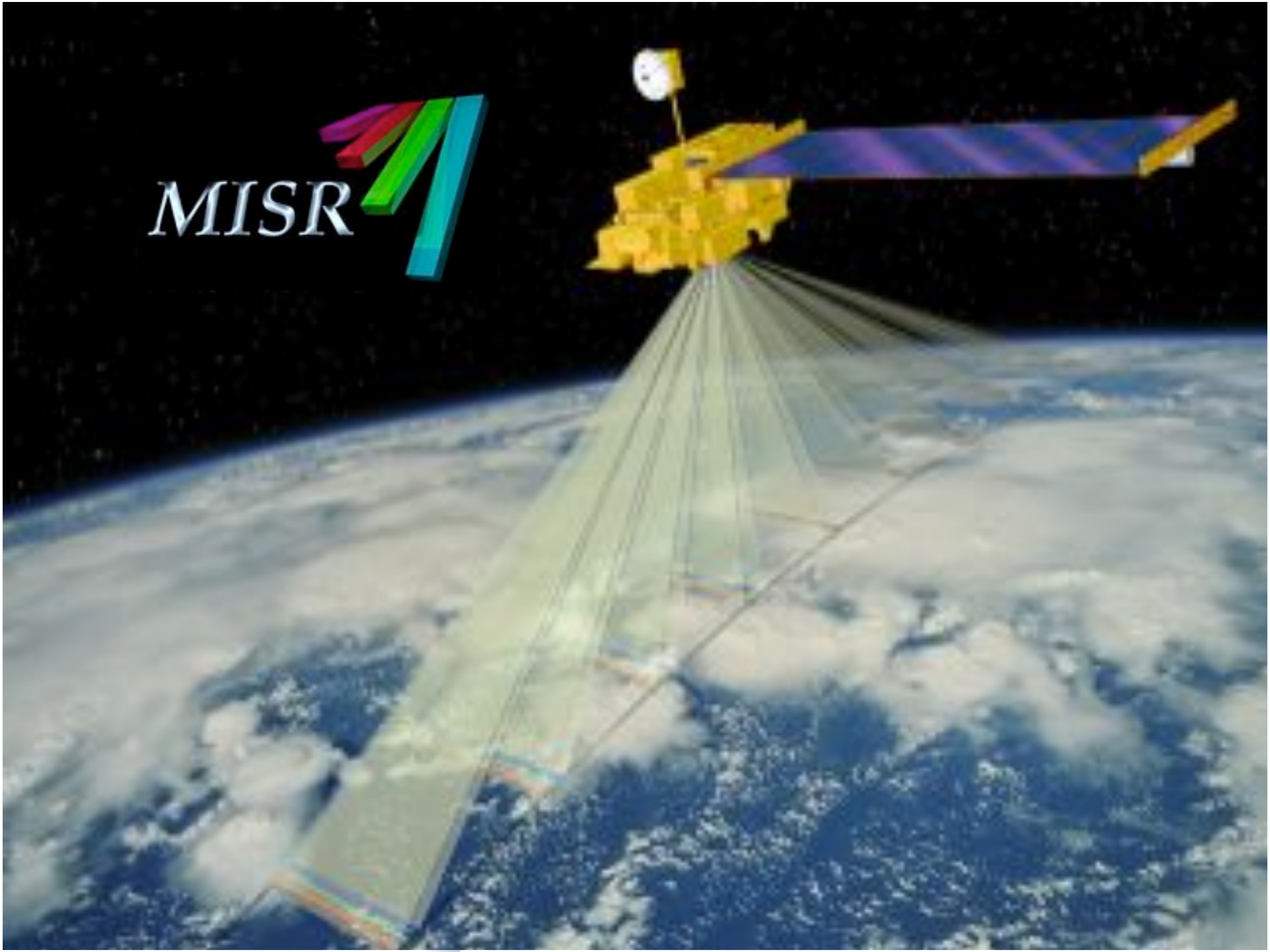
MISR overview and observational principles
Data products
Example data applications

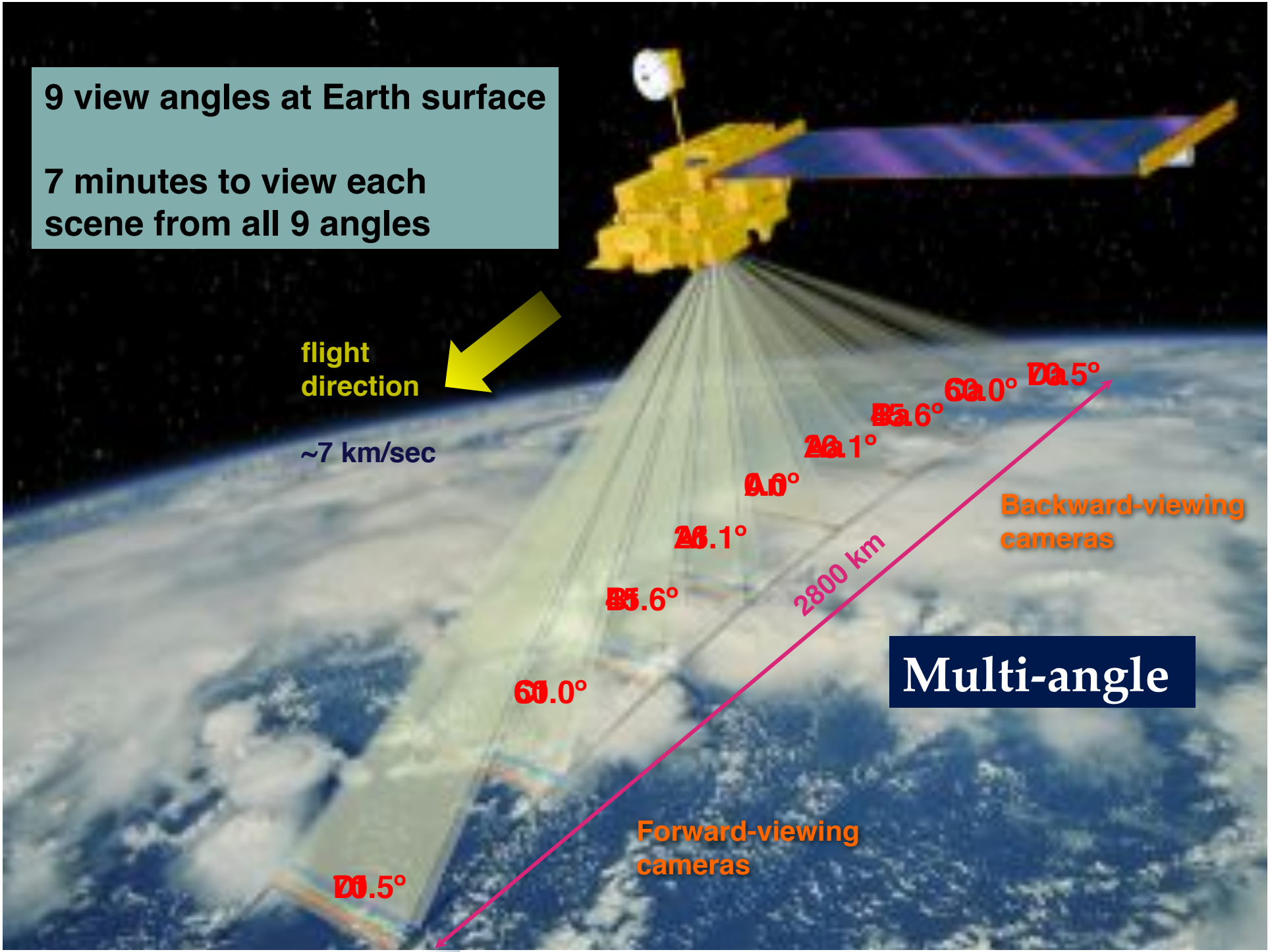
David J. Diner
Jet Propulsion Laboratory,
California Institute of Technology

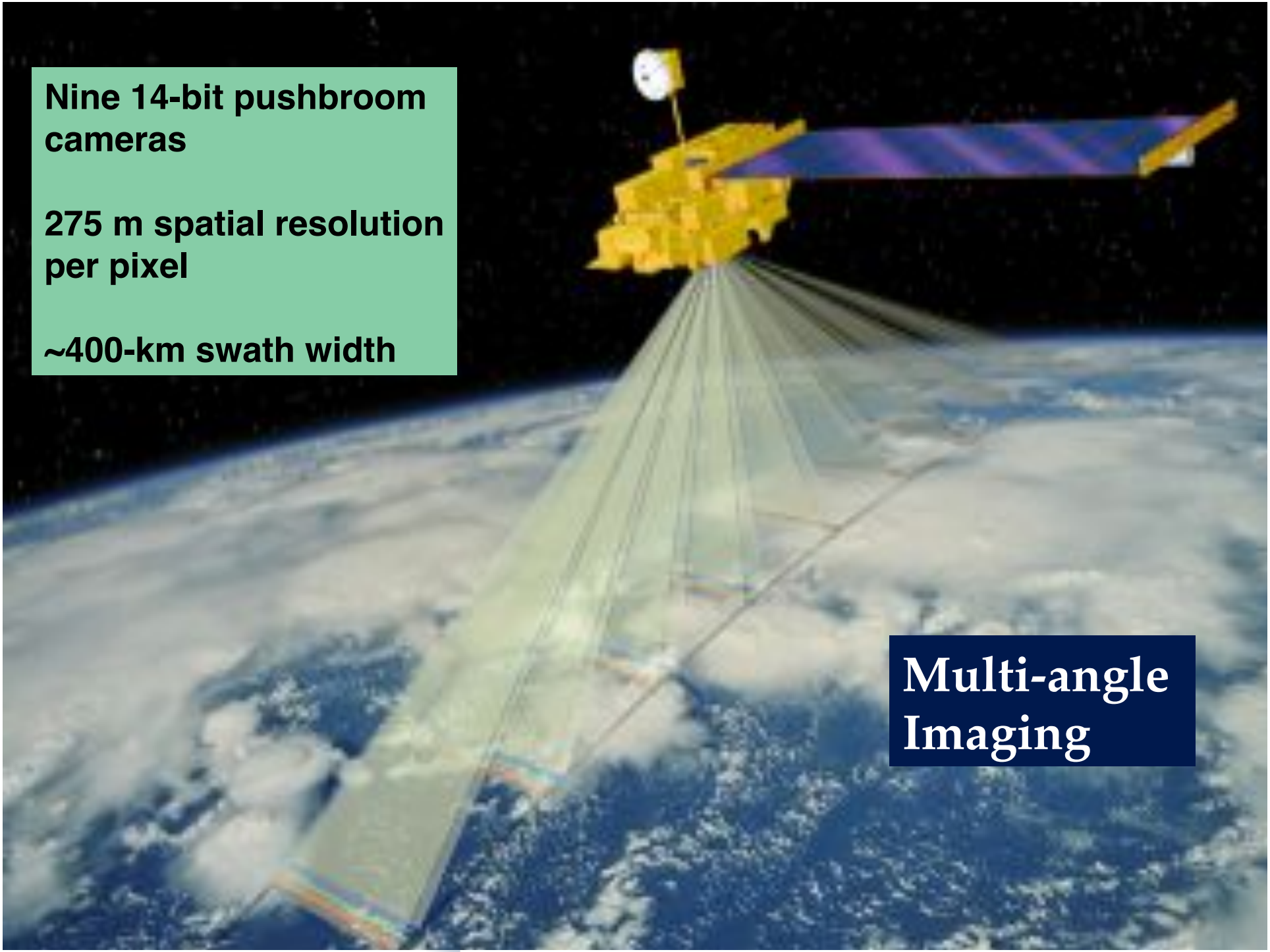
Exploring and Using MISR Data
Montreal, Quebec, Canada
May 2004

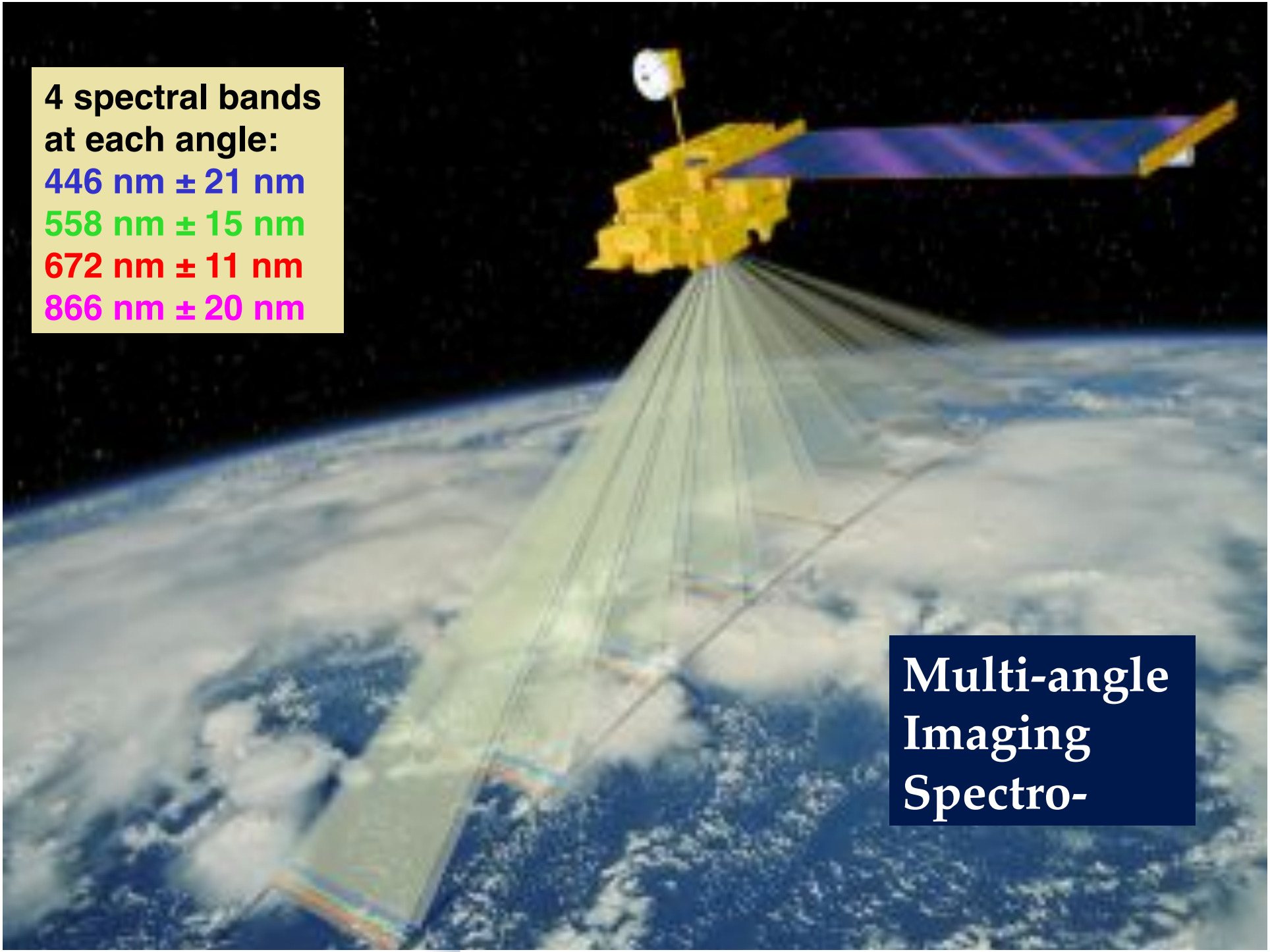
JPL

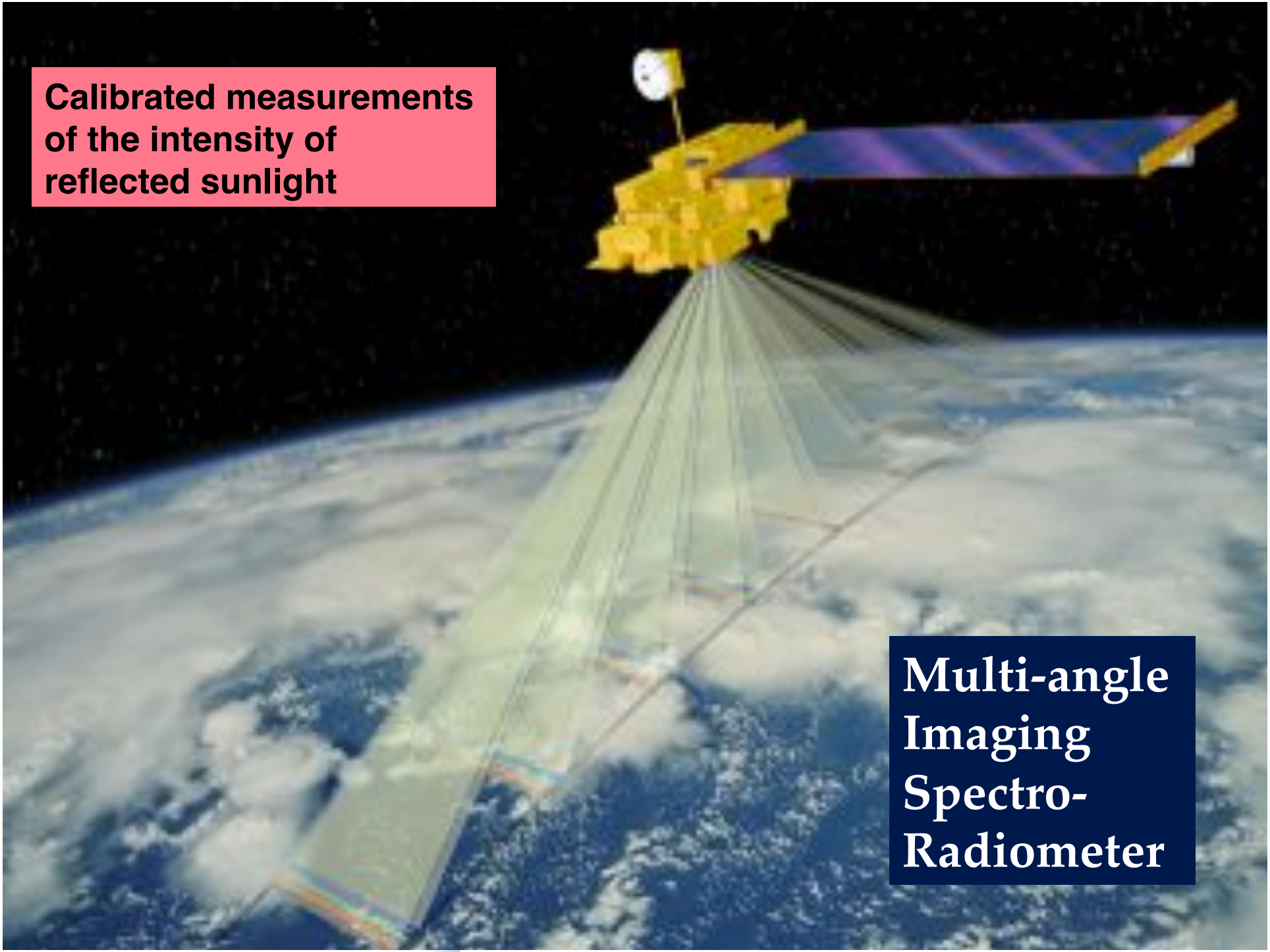
NASA




9 view angles at Earth surface
7 minutes to view each scene from all 9 angles
flight direction
~7 km/sec
Backward-viewing cameras
2800 km
Multi-angle
Forward-viewing cameras





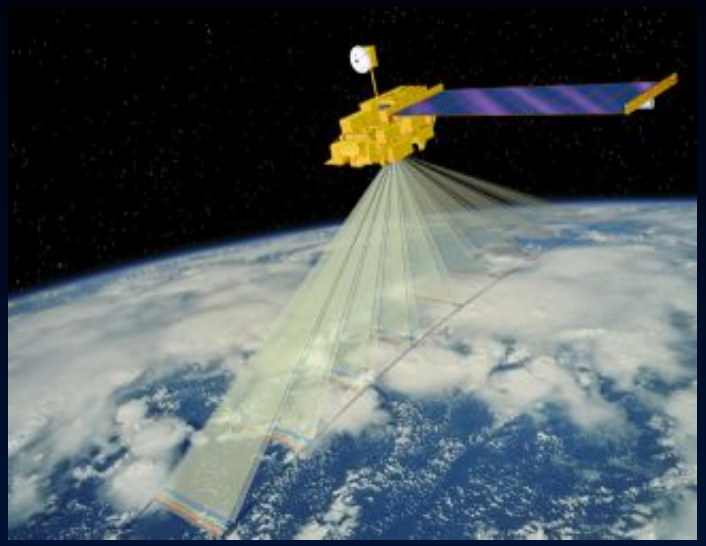

Calibrated measurements of the intensity of reflected sunlight
Multi-angle Imaging Spectro-Radiometer

Why multi-angle?

1. Change in brightness, color, and contrast with angle helps distinguish different types of surfaces, clouds, and airborne particles (aerosols)

2. Oblique slant paths through the atmosphere enhance sensitivity to aerosols and thin cirrus

3. Changing geometric perspective provides 3-D views of clouds



4. Time lapse from forward to backward views makes it possible to use clouds as tracers of winds aloft

5. Different angles of view enable sunglint avoidance or accentuation

6. Integration over angle is required to estimate hemispherical reflectance (albedo) accurately

Example areas of research

What is the abundance and distribution of different aerosol types, and how are these related to source locations and characteristics?

How does the surface respond to climate change or other disturbances? How does vegetation canopy structure affect photosynthetic and shortwave radiation fluxes?

How does 3-dimensional cloud structure affect our ability to relate cloud hydrological and radiative properties?

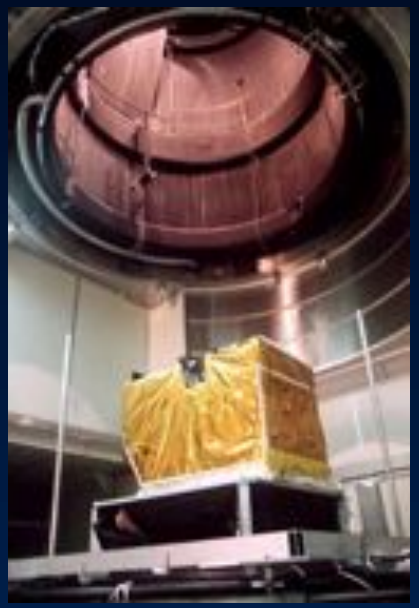
New ways of using MISR data are still likely to be discovered.

MISR instrument

Family portrait

The “V-9” optical bench

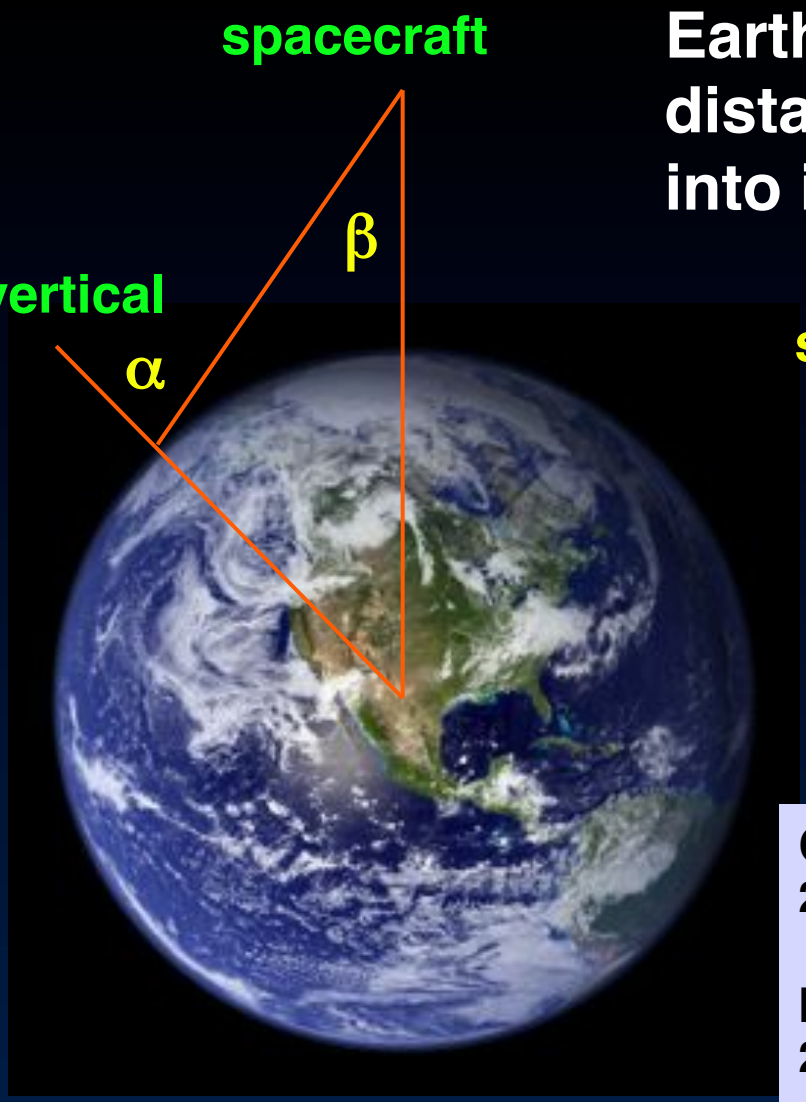
Undergoing test



JPL’s Space Simulator Facility

MISR on Terra spacecraft

Terra launch 18 December 1999



Earth curvature and viewing distance are factored into instrument design

$$\sin \beta = \frac{R \sin \alpha}{R + h}$$

R = Earth radius
h = spacecraft altitude

Example:
$\alpha = 70.5°$, $\beta = 58.0°$

Cross-track footprint
250 m nadir; 275 m off-nadir

Instantaneous along-track footprint
214 - 700 m from nadir to 70°

Along-track sampling
275 m at every angle (i.e., off-nadir angles are oversampled)

MISR's nine cameras consist of four unique refractive lens designs of different focal lengths

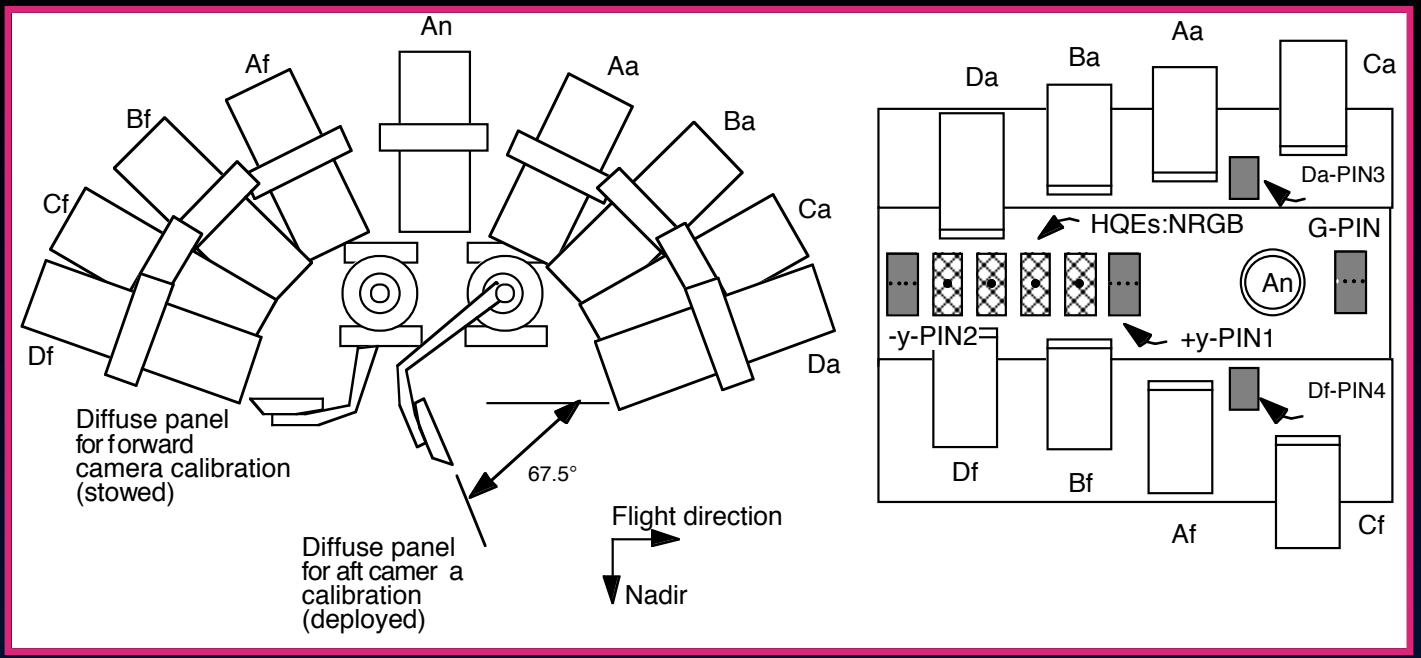
Earth rotation is factored into instrument design

Terra orbit

forward and backward views are a few minutes apart

camera pointing directions have slight east-west offsets to maximize swath overlap and compensate for Earth rotation

Radiometric and geometric calibration

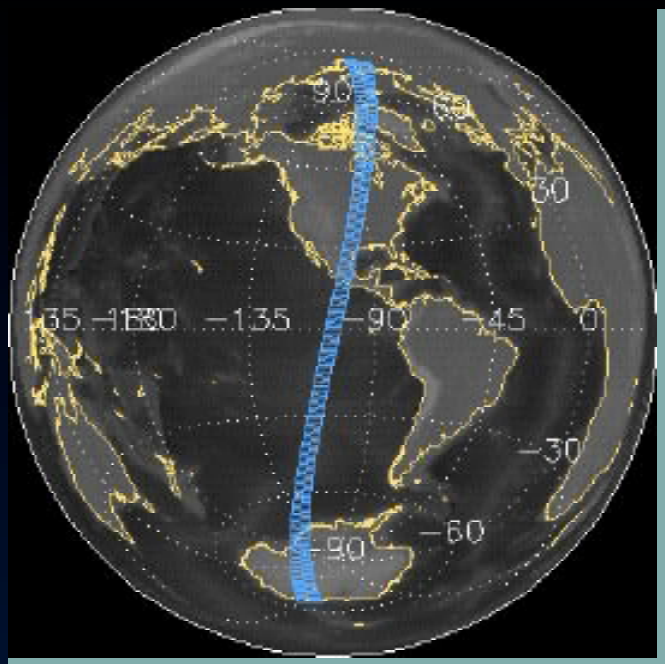


On-board calibrator (OBC):

- Deployable Spectralon panels monitored by stable photodiodes
- Provides camera flat-fielding, camera-to-camera and band-to-band calibration, and temporal stability
- Supplemented by vicarious field calibrations to establish absolute scale

Camera geometric models (CGM's) are established using image tie-pointing between MISR and Landsat

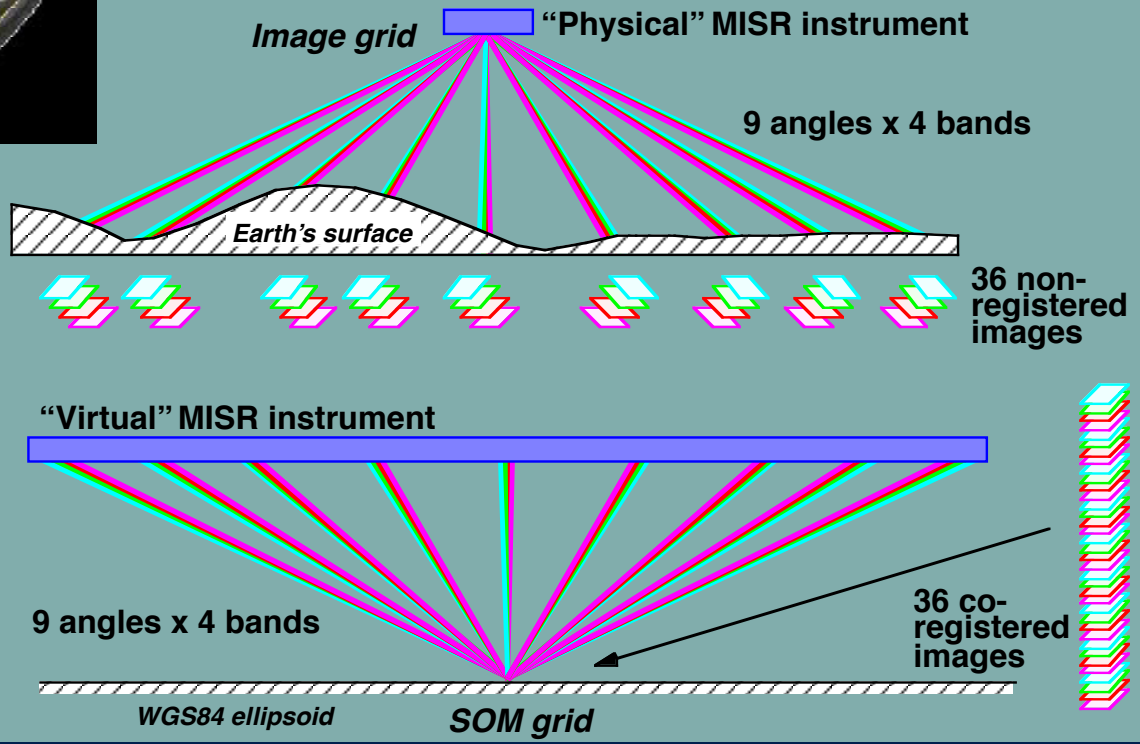
- CGM's are used in the automated map projection of MISR data



Calibration, geolocation, resampling, and co-registration occurs during Level 1 processing

Space Oblique Mercator projection

233 unique paths in 16-day repeat-cycle of Terra orbit



Instrument science modes

Global

- Pole-to-pole coverage on orbit dayside
- Full resolution in all 4 nadir bands, and red band of off-nadir cameras (275-m sampling)
- 4x4 pixel averaging in all other channels (1.1-km sampling)

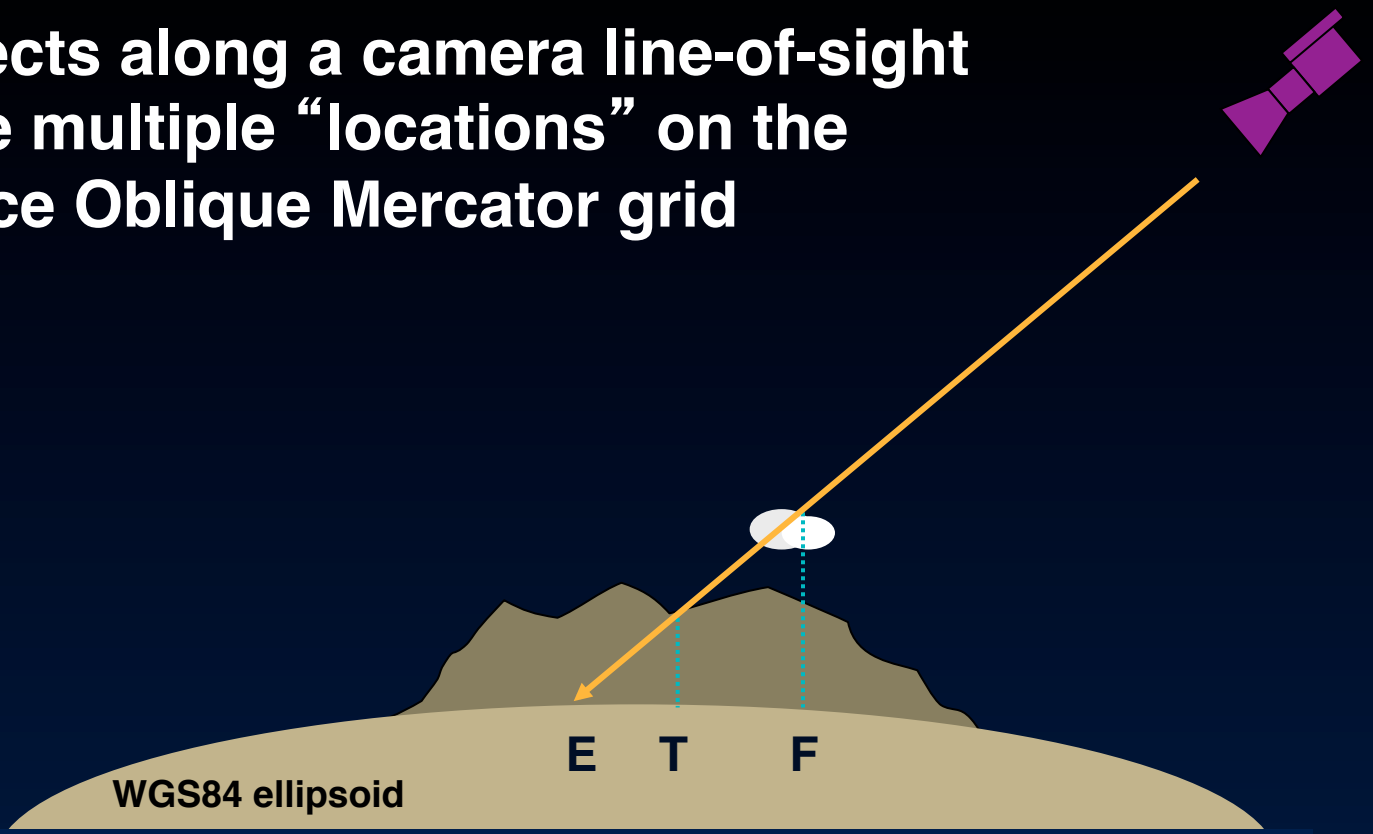
Local

- Implemented for pre-established targets (1-2 per day)
- Provides full resolution in all 36 channels (275-m sampling)
- Pixel averaging is inhibited sequentially from camera Df to camera Da over targets approximately 300 km in length

Calibration

- Implemented bi-monthly
- Spectralon solar diffuser panels are deployed near poles and observed by cameras and a set of stable photodiodes

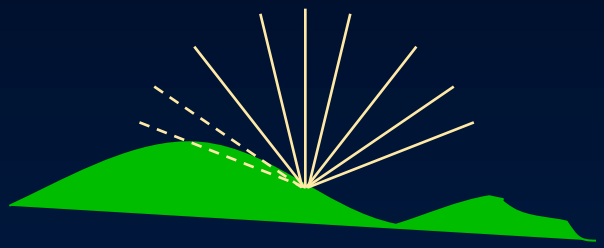
Objects along a camera line-of-sight have multiple “locations” on the Space Oblique Mercator grid



E = ellipsoid-projected location
T = terrain-projected location
F = feature-projected location

Camera-to-camera co-registration requires establishing a reference altitude

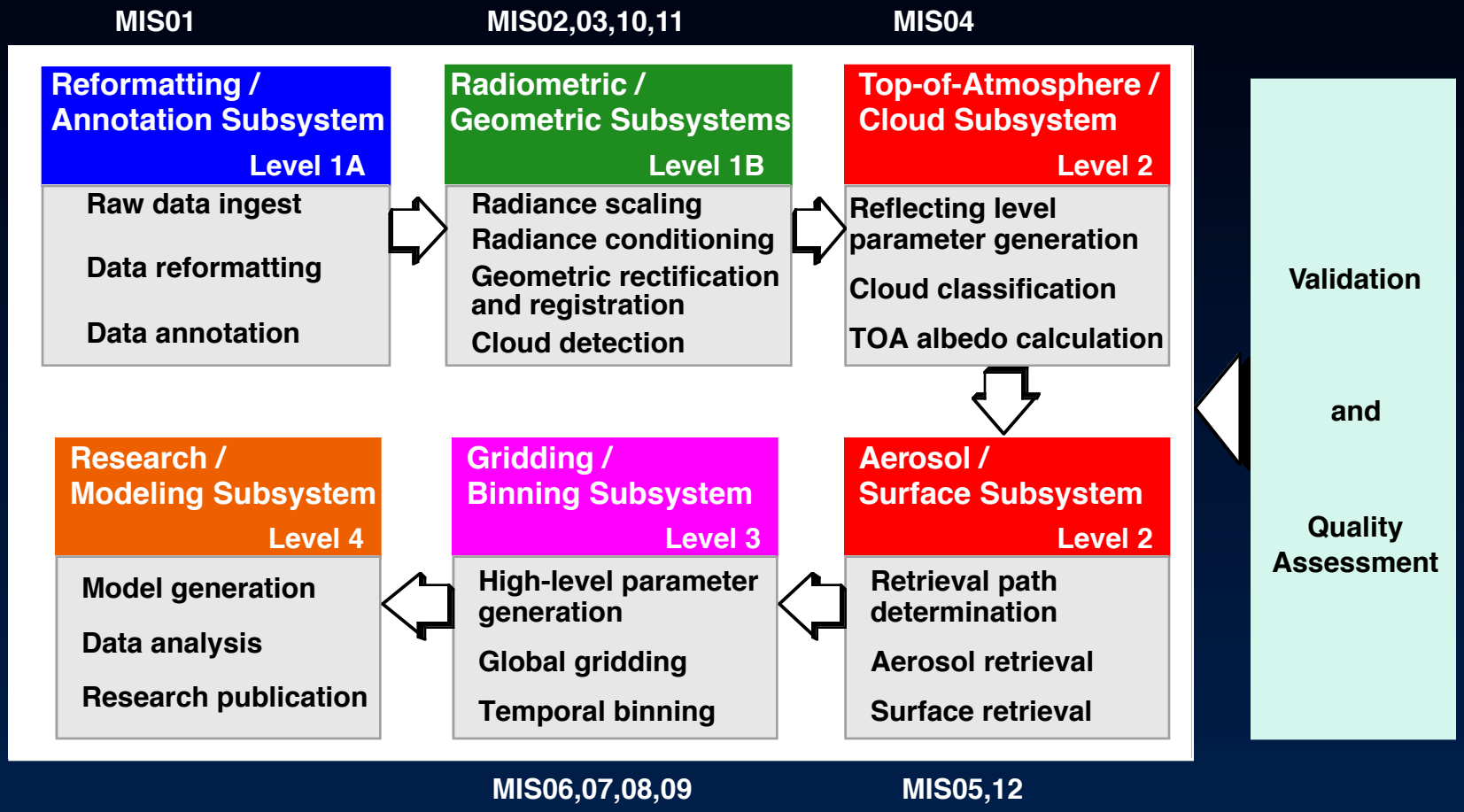
"Ellipsoid projection" is to the WGS84 ellipsoid
- performed during Level 1 processing
- used as input to stereoscopic processing



"Terrain projection " is to a digital elevation model
- performed during Level 1 processing
- used as input to aerosol/surface processing
- some views may be obscured

"Feature projection" uses stereoscopically derived cloud heights
- performed during Level 2 processing
- used as input to albedo and cloud classifiers processing

MISR data product generation



Data maturity levels

Terra data products are given the following maturity classifications:

Beta: Minimally validated. Early release to enable users to gain familiarity with data formats and parameters. May contain significant errors.

Provisional: Partially validated. Improvements are continuing. Useful for exploratory studies.

Validated: Uncertainties are well defined, and suitable for systematic studies.

Mapping of data product maturity to version numbers found at:
http://eosweb.larc.nasa.gov/PRODOCS/misr/Version/version_stmt.html

Level 1 Standard Products

Level 1 standard products

- Level 1A reformatted, annotated product
- Level 1B1 radiometric product
- Level 1B2 georectified radiance product, in two flavors:
  - ellipsoid
  - terrain (blocks containing land only)
- Level 1B2 browse (JPEG)
- Level 1B2 geometric parameters
- Level 1B2 radiometric camera-by-camera cloud mask

Space Oblique Mercator is used as the projection to minimize resampling distortions

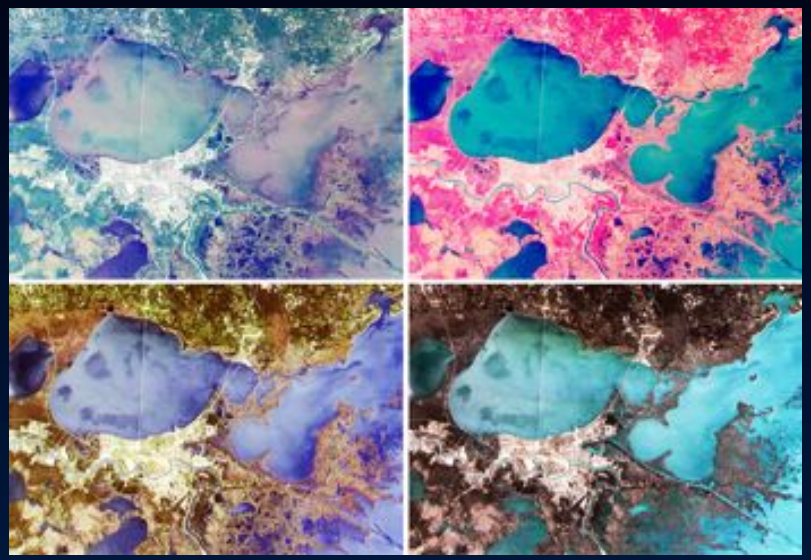
Level 1 processing operates on each camera individually

A data "granule" is an entire pole-to-pole swath

L1B2 Georectified Radiance Product (MIS03)

Georectified (Earth-projected) radiance data

PRODUCT MATURITY:
VALIDATED



Multi-spectral, multi-angle composites of New Orleans and the Gulf Coast, 15 October 2001

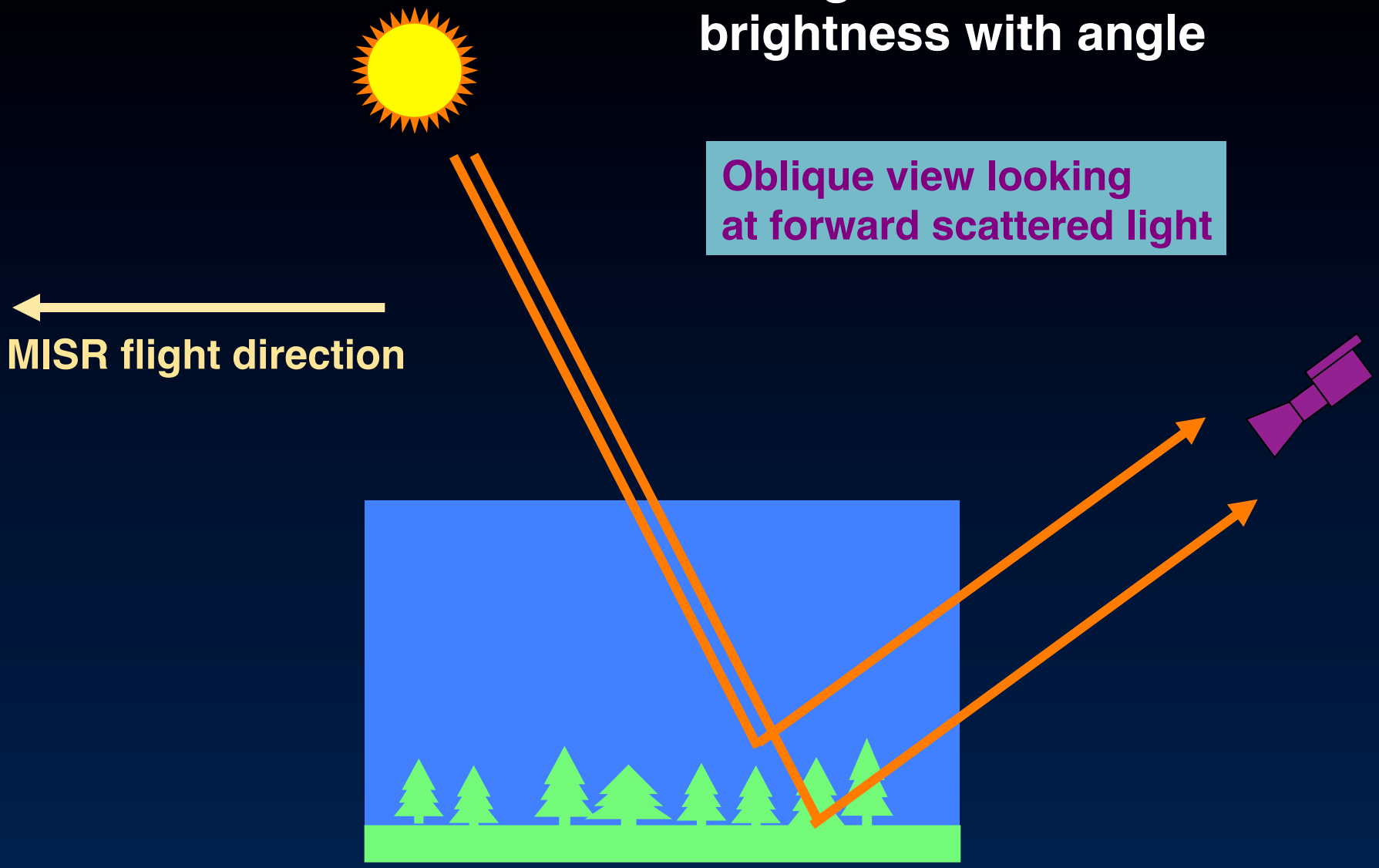
PRODUCT QUALITY

- Absolute radiometry ±4%
- Band-to-band, camera-to-camera ±2%
- Mean geolocation error < 45 m
- 8 of 9 cameras typically co-register to < 1 pixel; Da camera shows time-variable co-registration errors of up to 2 pixels typically
- Reference Orbit Imagery has been implemented to provide consistently stable camera co-registration
- Orbit attitude and ephemeris quality flag included in product
- Scale factors to convert radiances to top-of-atmosphere BRF's included in product

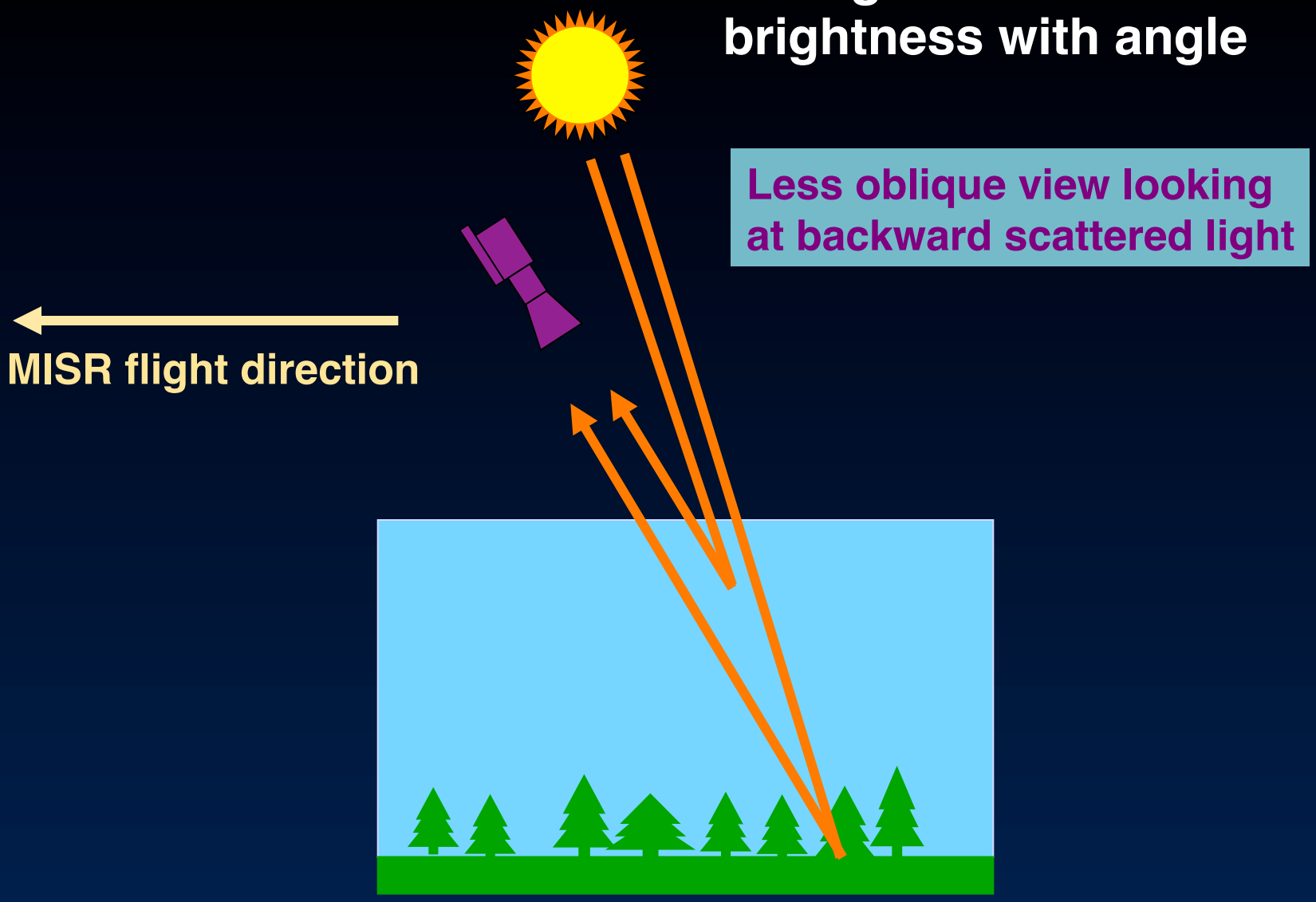

50 km
James Bay, Canada
9 August 2000
Nadir red, green, blue


50 km
James Bay, Canada
16 January 2001
Nadir red, green, blue

Changes in scene brightness with angle



Changes in scene brightness with angle

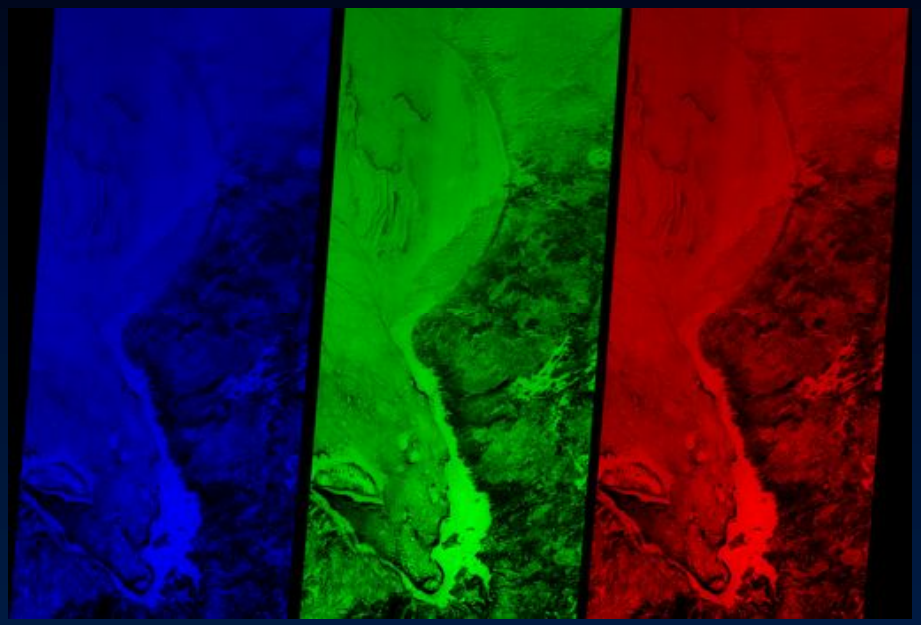


Visualizing surface characteristics

nadir
blue band

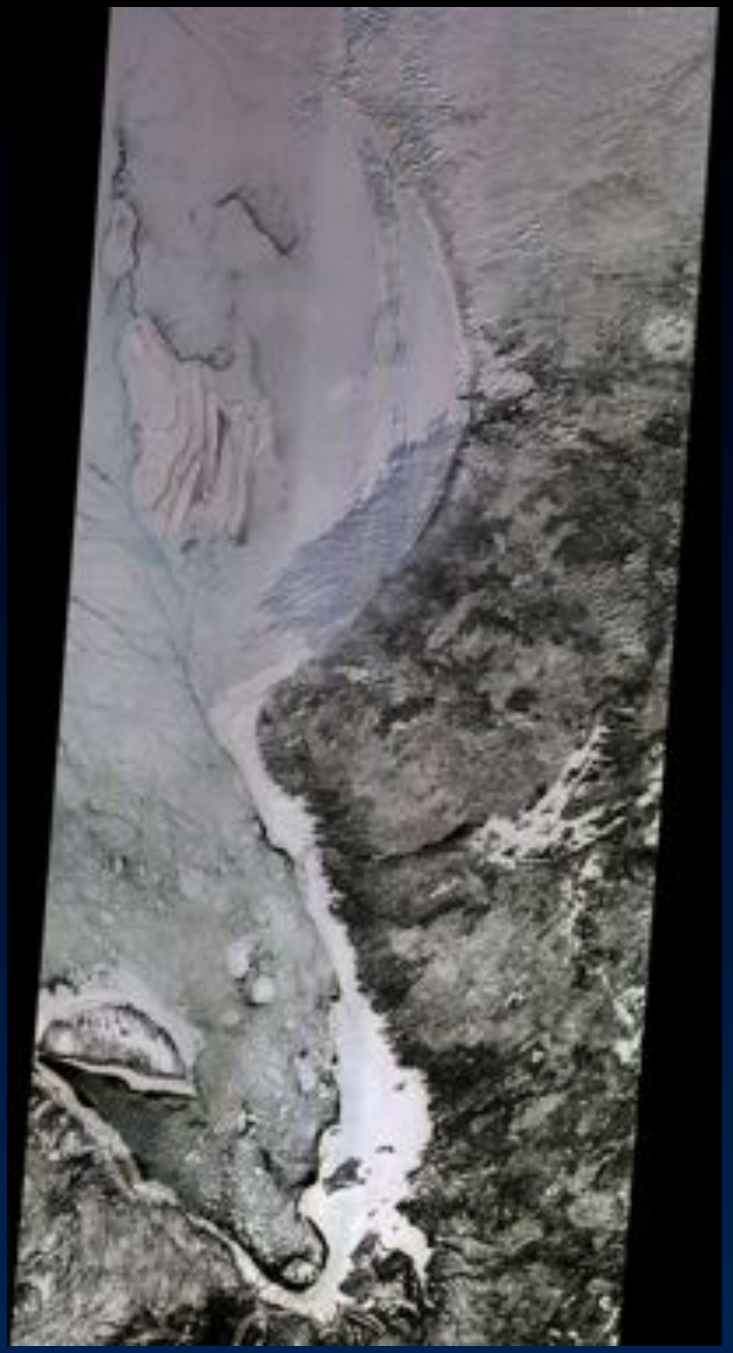
nadir
green band

nadir
red band



multi-spectral compositing

Hudson and
James Bays
24 February 2000

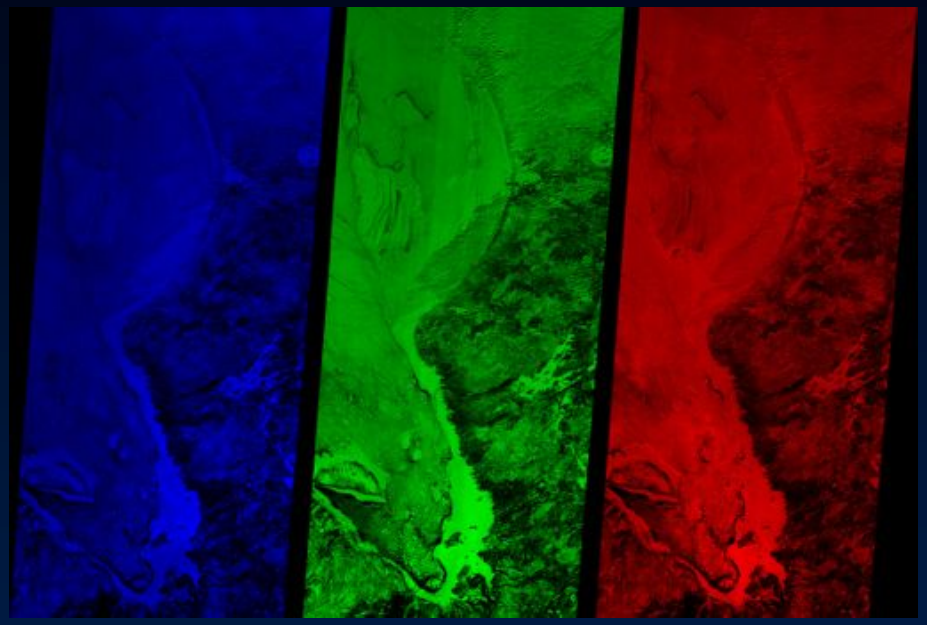


Visualizing surface characteristics

70° forward red band

nadir red band

70° backward red band

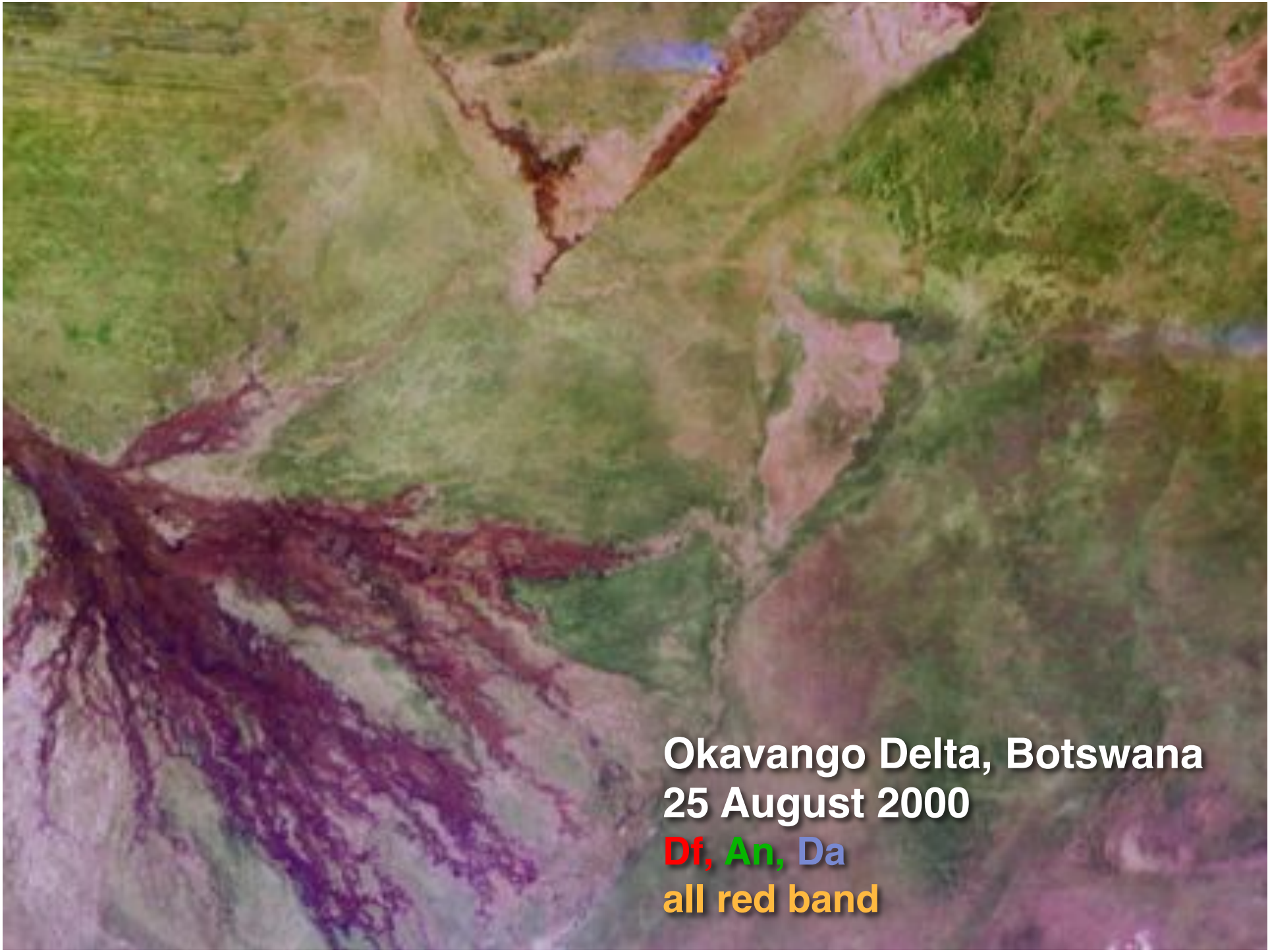


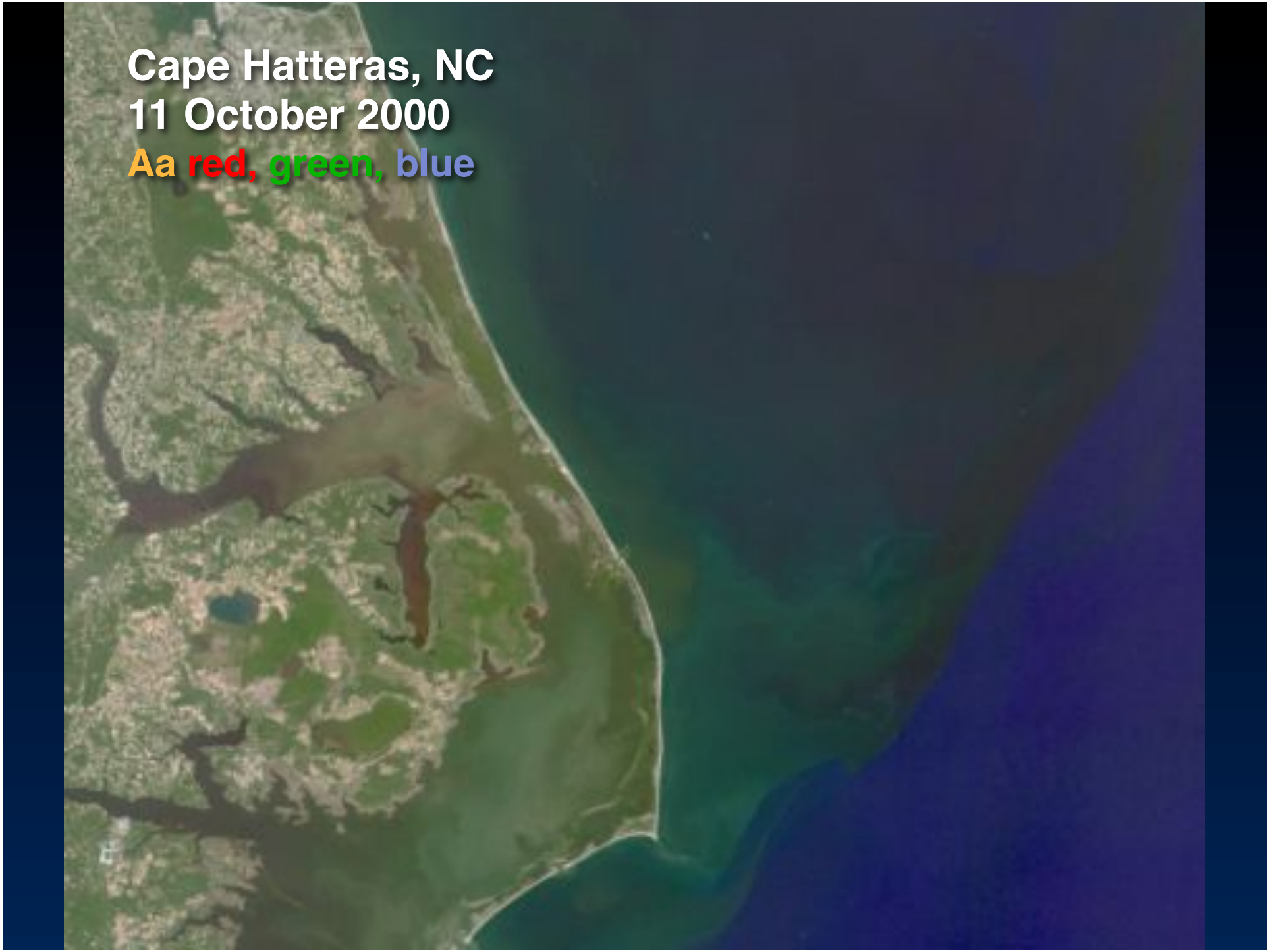
multi-angular compositing

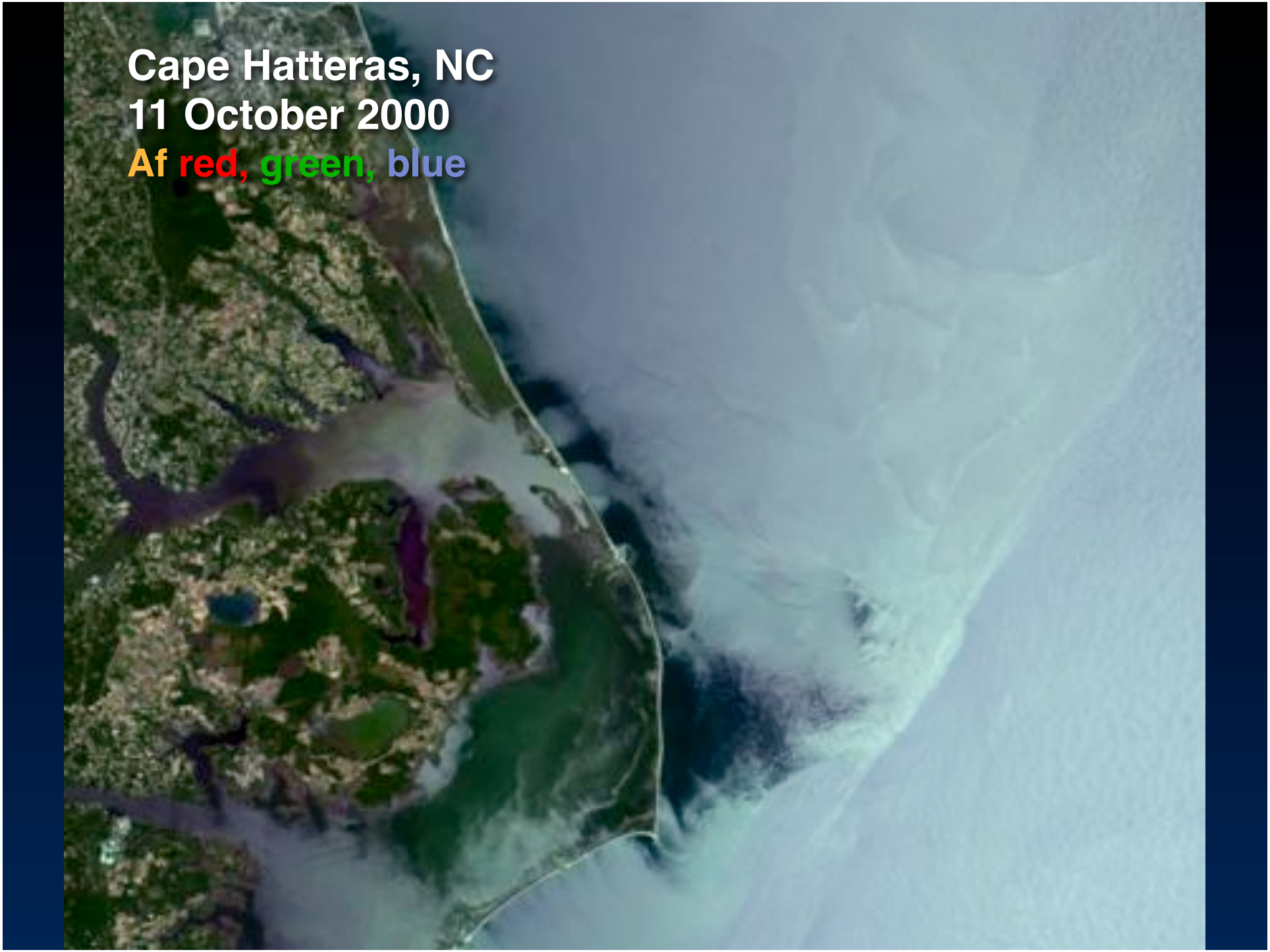
Hudson and James Bays
24 February 2000


Okavango Delta, Botswana
25 August 2000
An red, green, blue


Okavango Delta, Botswana
25 August 2000
An NIR, red, green


Okavango Delta, Botswana
25 August 2000
Df, An, Da
all red band

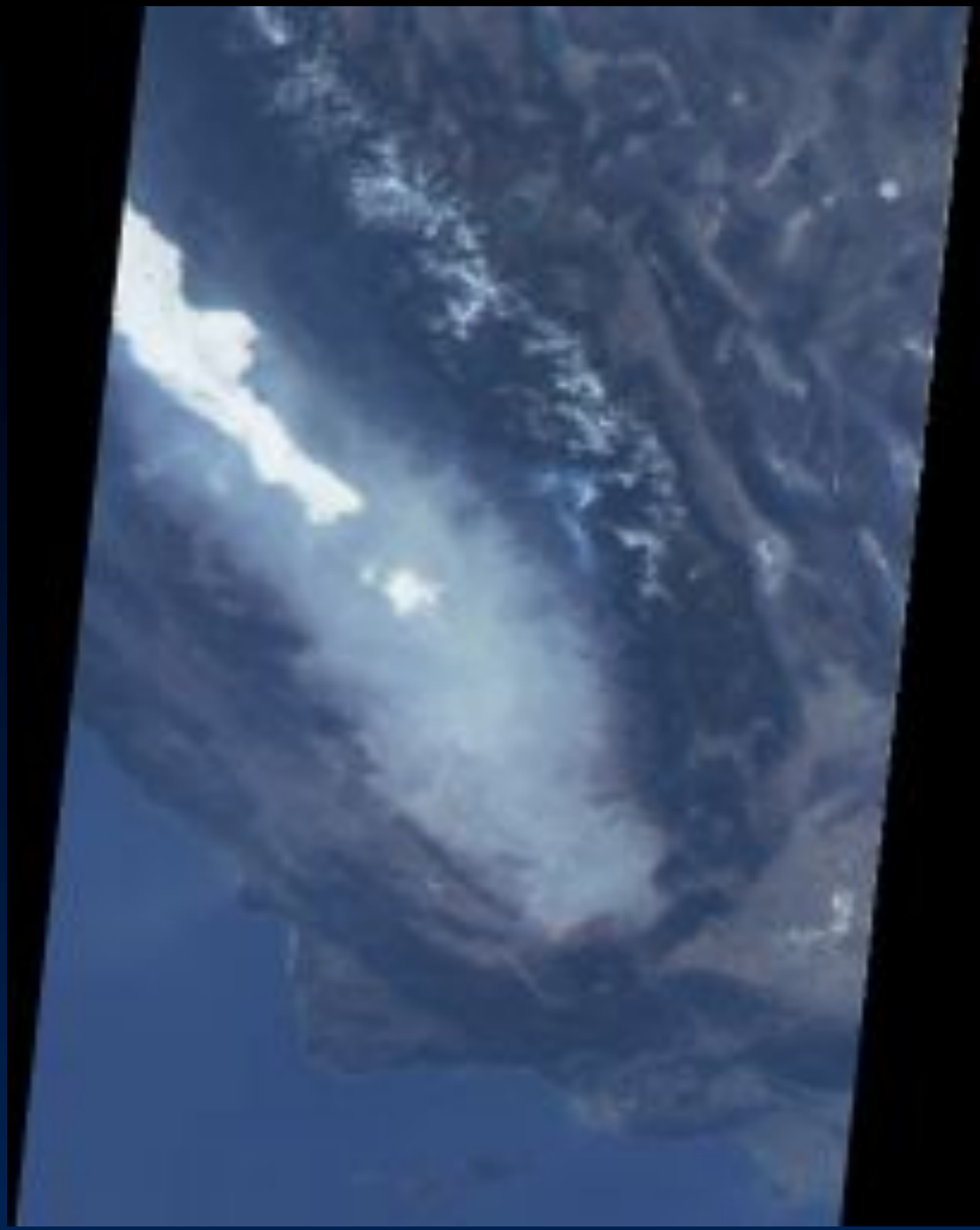

Cape Hatteras, NC
11 October 2000
Aa red, green, blue


Cape Hatteras, NC
11 October 2000
Af red, green, blue


Cape Hatteras, NC
11 October 2000
Cf red, green, blue

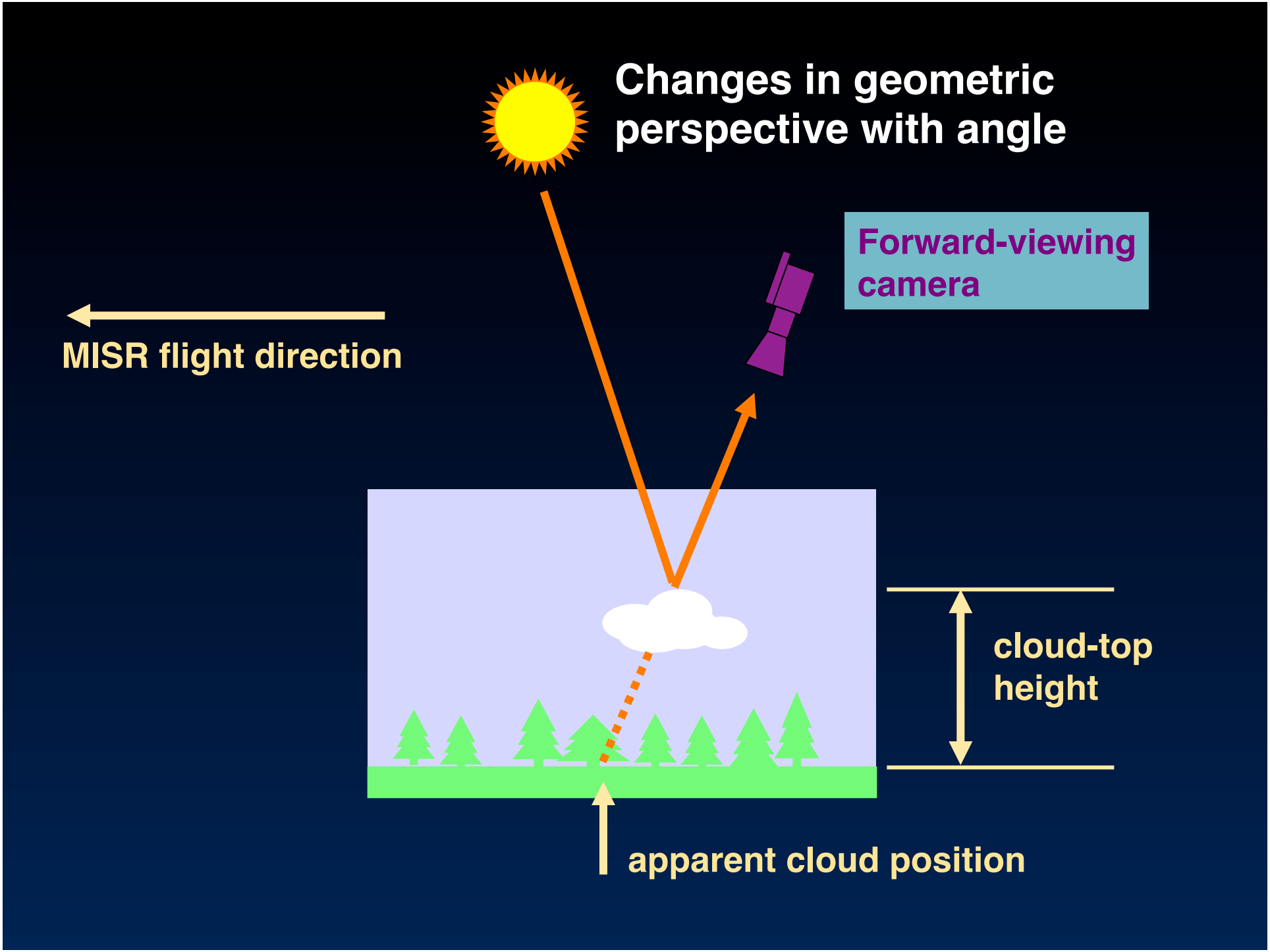
San Joaquin Valley
3 January 2001

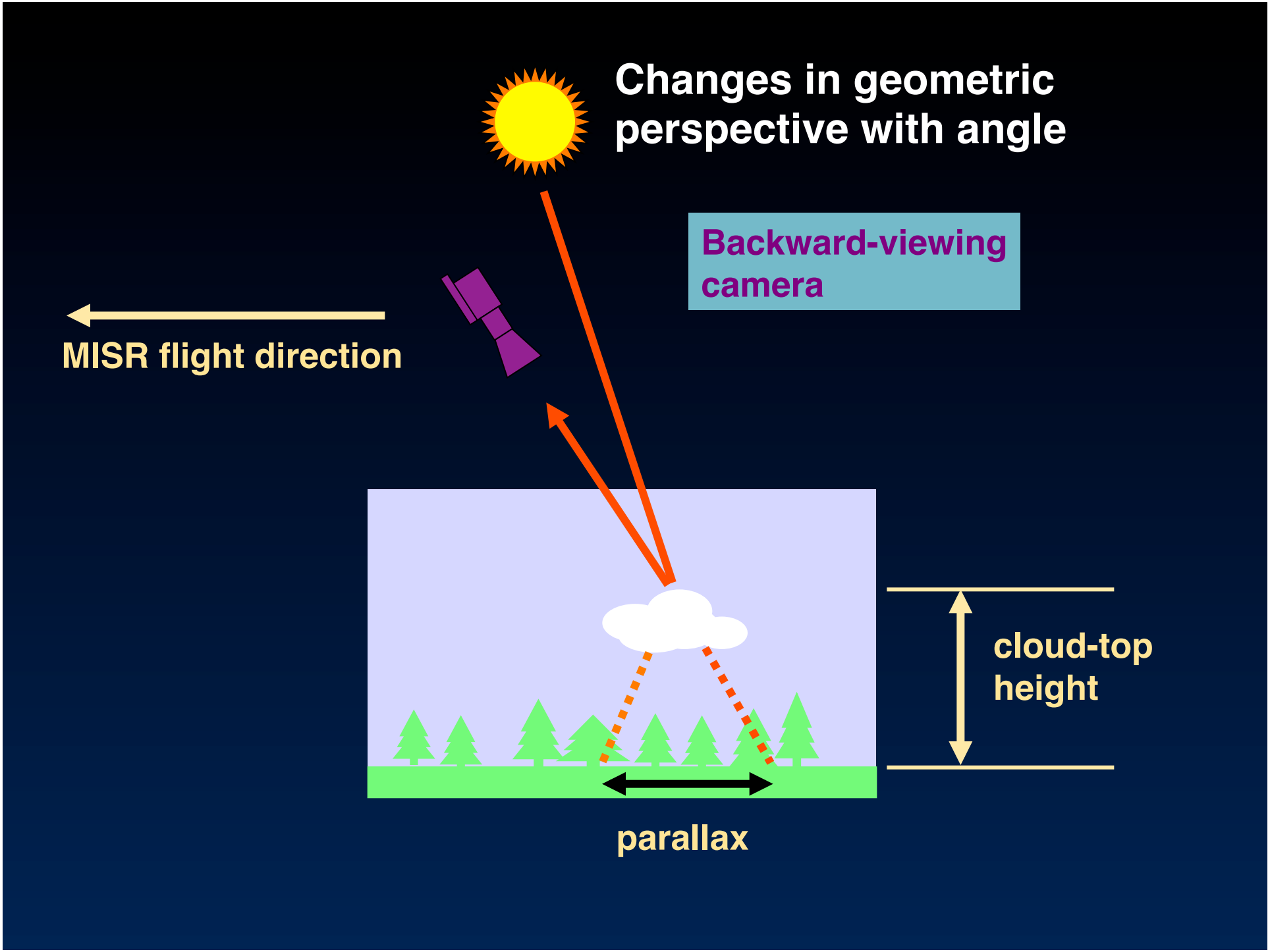
Nadir (An)

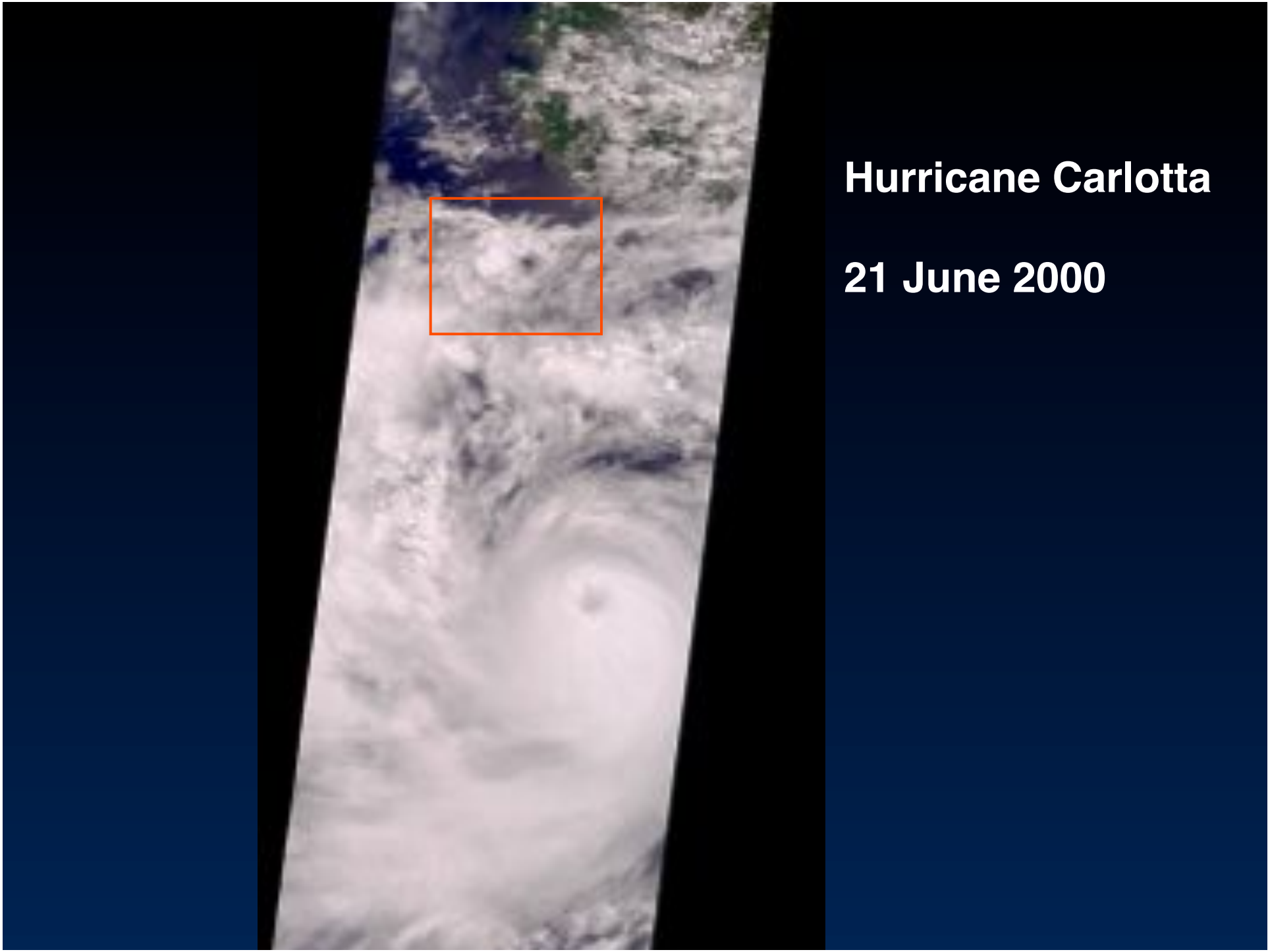


San Joaquin Valley
3 January 2001

70° forward (Df)


Changes in geometric perspective with angle
Forward-viewing camera
MISR flight direction
cloud-top height
apparent cloud position

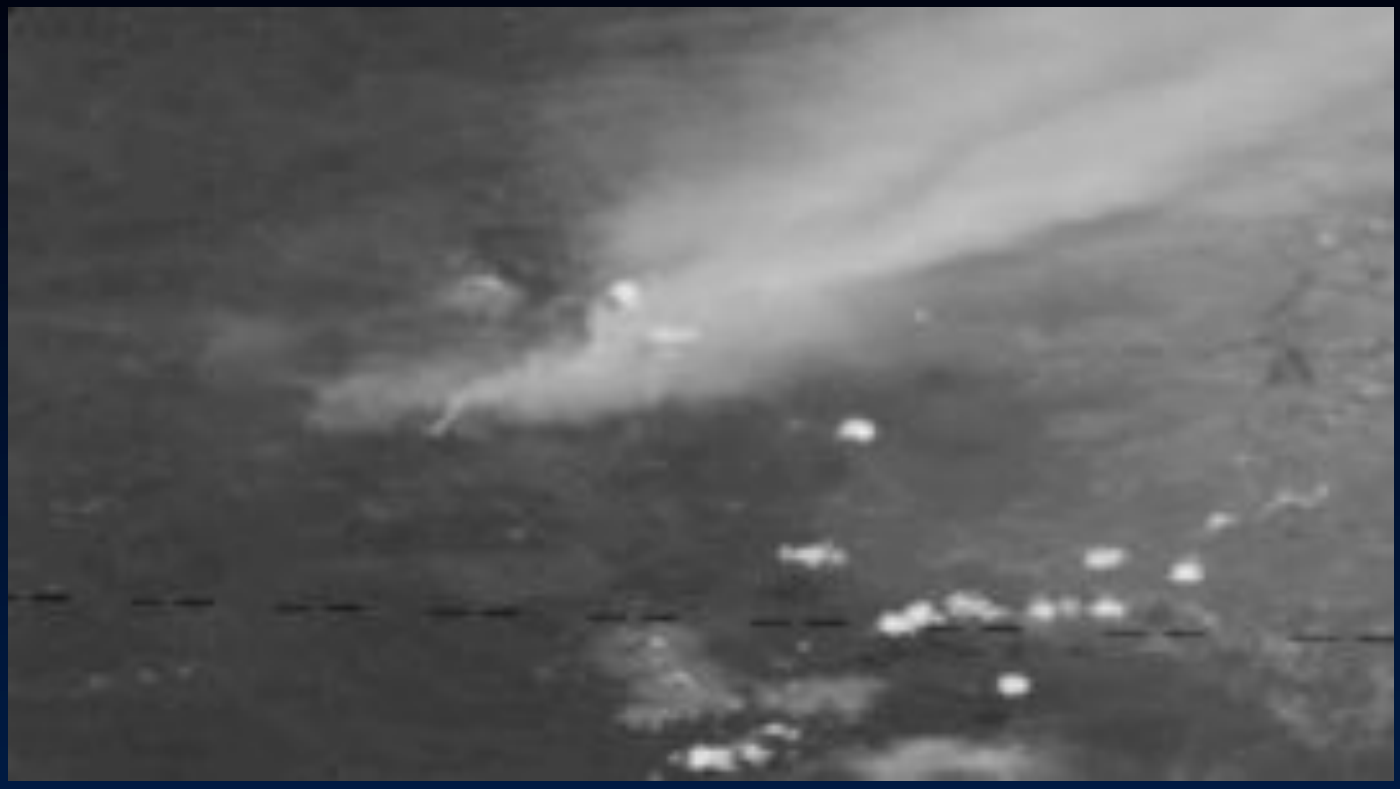

Changes in geometric perspective with angle
Backward-viewing camera
MISR flight direction
cloud-top height
parallax


Hurricane Carlotta
21 June 2000

Multi-angle "fly-over" of Hurricane Carlotta thunderclouds

19 August 2000

Perspective views from 5 angles



B&B Complex Fire, Oregon
4 September 2003

Georgian Bay, Ontario, 6 March 2000

Nadir (An)

26° forward (Af)

Georgian Bay, Ontario, 6 March 2000

Nadir (An)

46° forward (Bf)

Georgian Bay, Ontario, 6 March 2000

Nadir (An)

60° forward (Cf)

Georgian Bay, Ontario, 6 March 2000

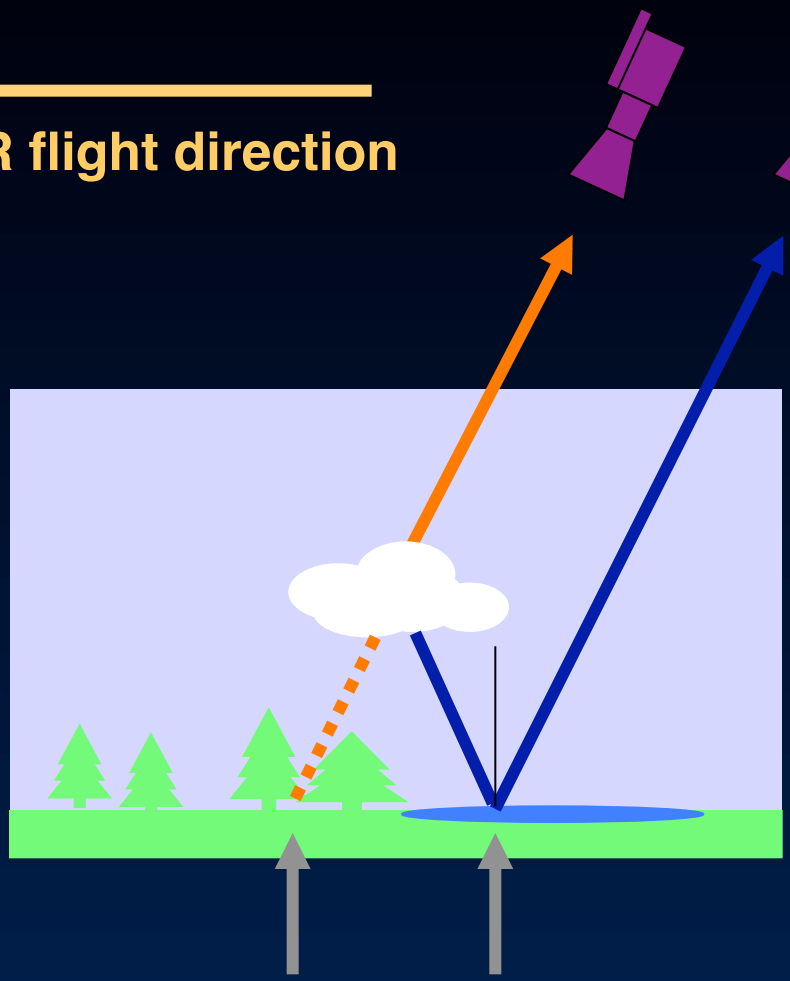
Nadir (An)

70° forward (Df)

Cloud reflection in water

Less oblique MISR camera

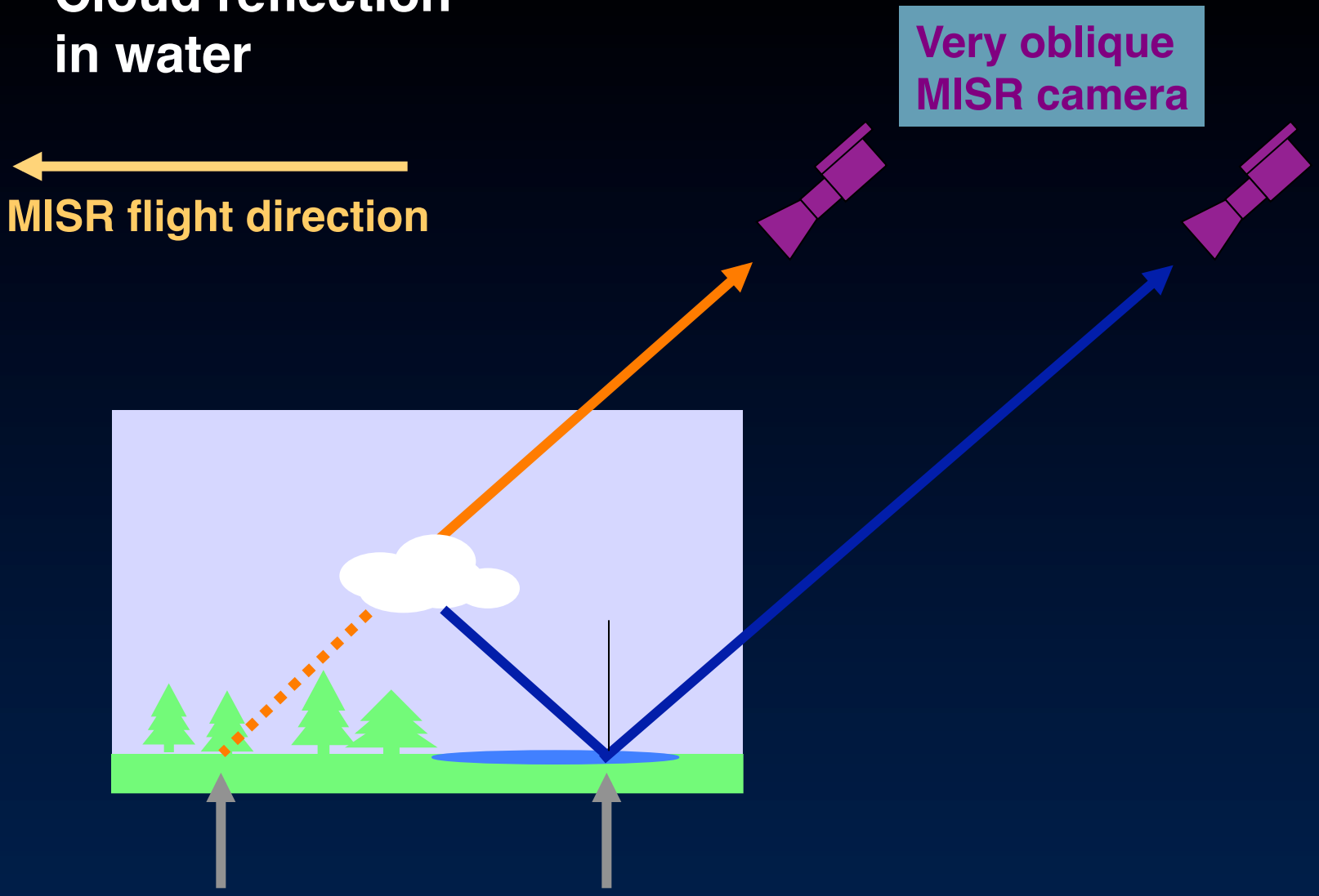
MISR flight direction

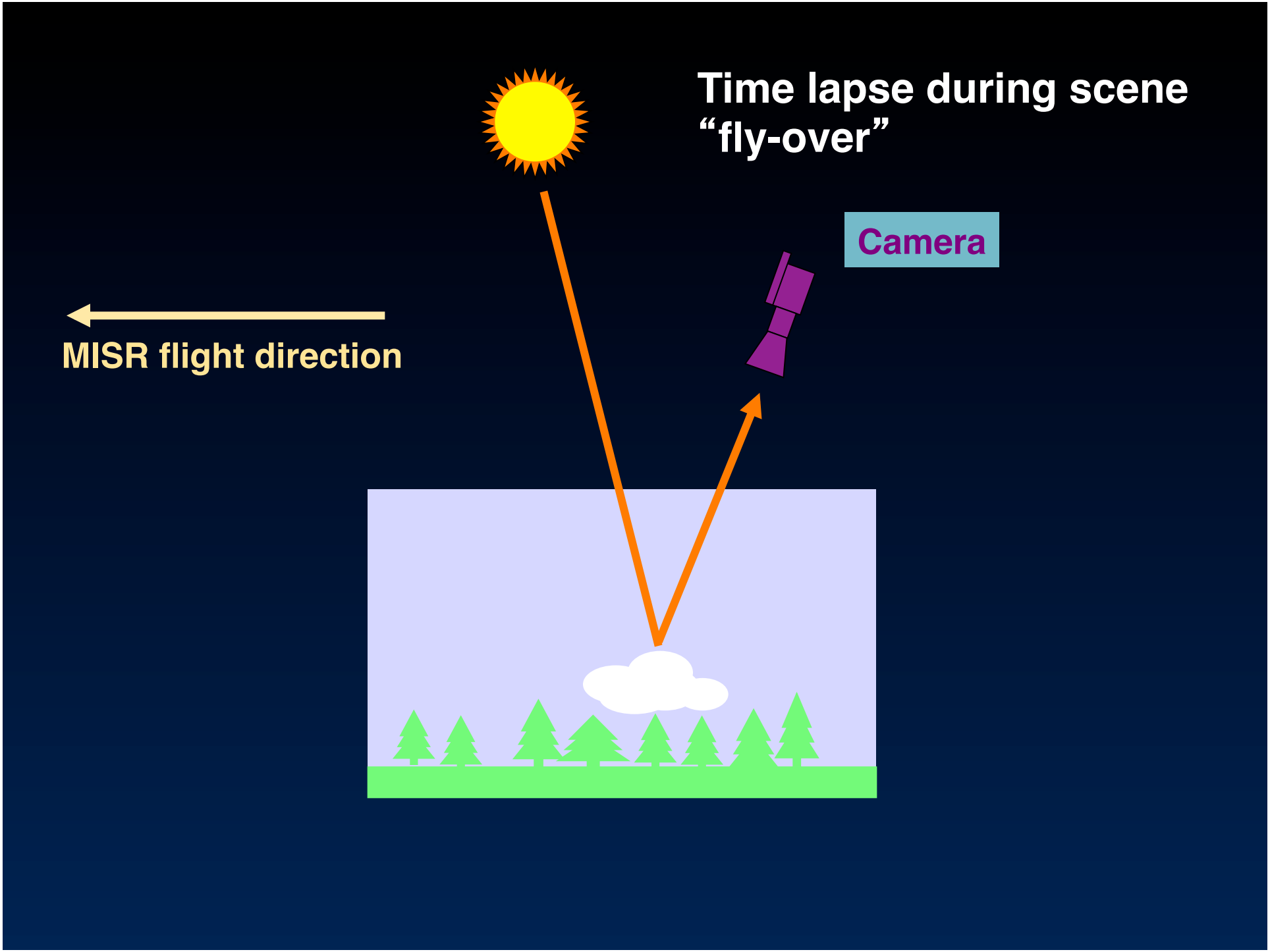


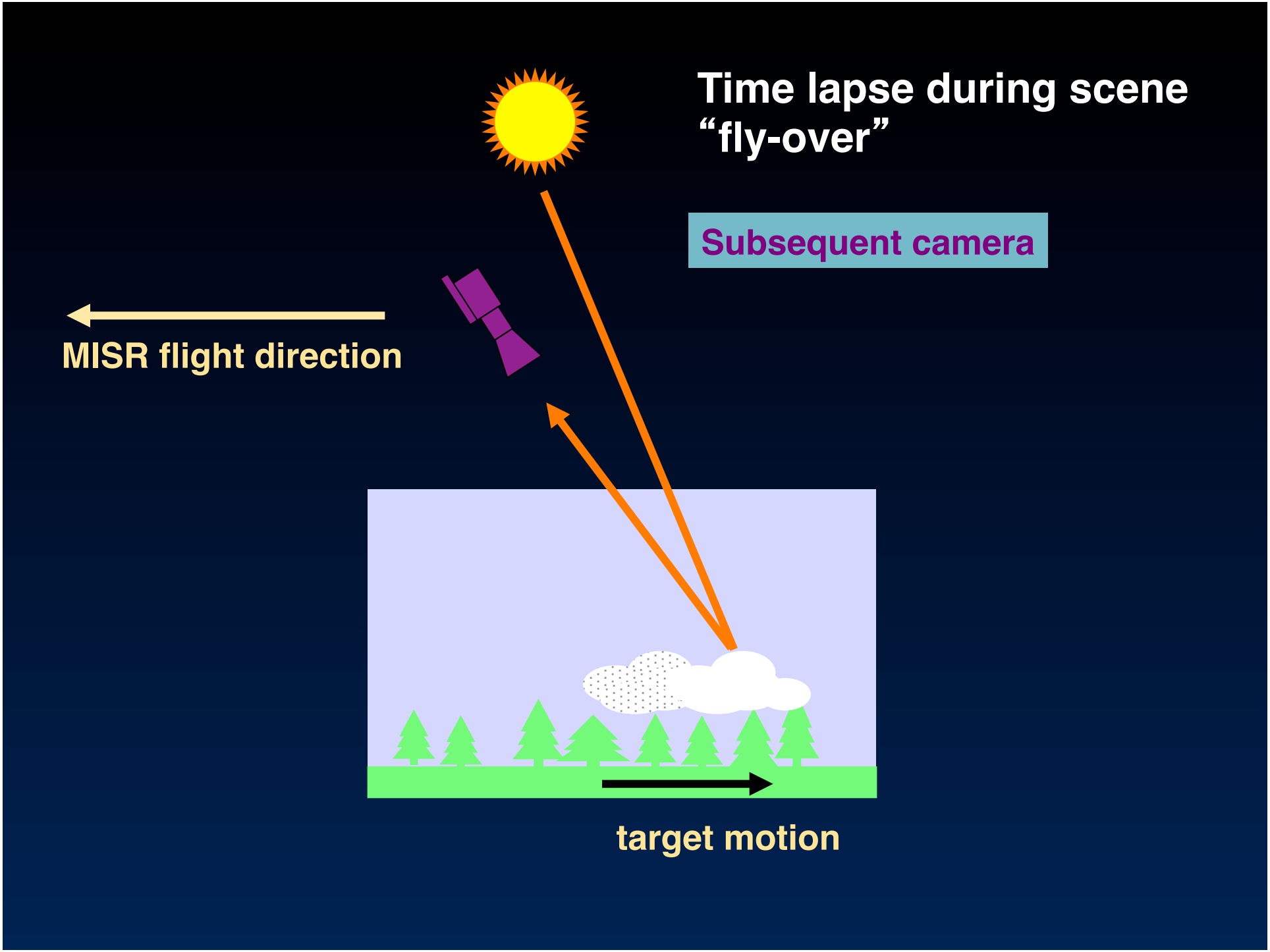
apparent cloud position

reflection position

Cloud reflection in water




Time lapse during scene
“fly-over”
Camera
MISR flight direction


Time lapse during scene
“fly-over”
Subsequent camera
MISR flight direction
target motion

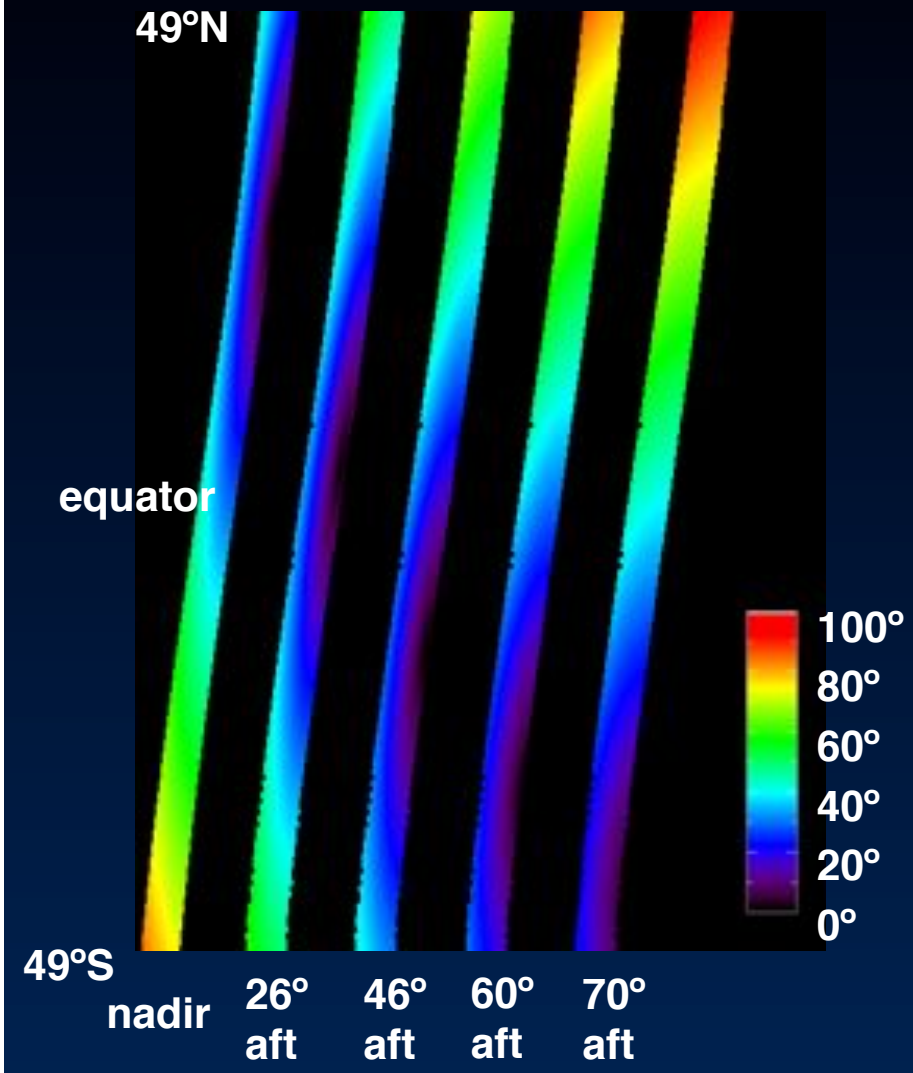
Moving ships off the North Carolina Coast

11 October 2000

Von Karman vortex street near Jan Mayen Island
6 June 2001

L1B2 Geometric Parameters (MIS03)

Provided on 17.6-km centers



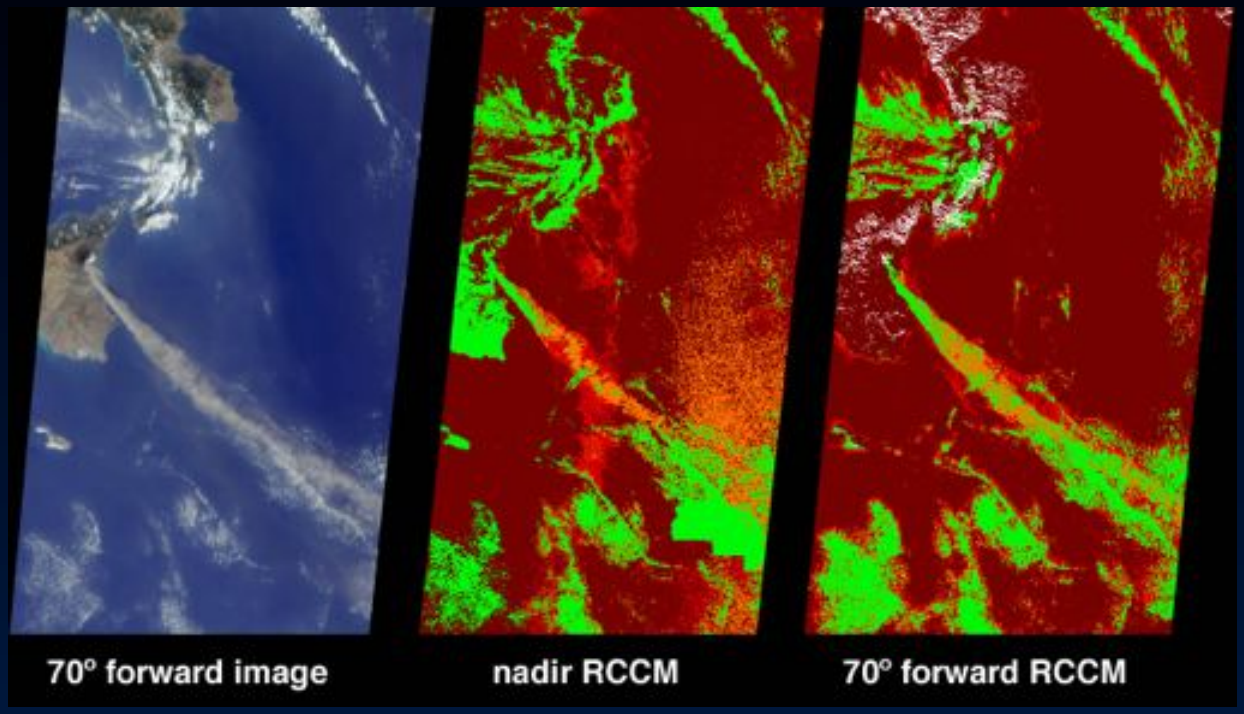
PRODUCT MATURITY: VALIDATED

- View zenith and azimuth angles per camera; azimuths measured relative to local north
- Solar zenith and azimuth angles correspond to midpoint viewing time of only those cameras which observed the point
- Scatter and glitter angles also included in product

Example of glitter angle July 3

L1B2 Radiometric Camera-by-camera Cloud Mask (MIS03)

Radiometric threshold-based cloud mask



Mt. Etna eruption,
22 July 2001

- No retrieval
- High confidence clear
- Low confidence clear
- Low confidence cloud
- High confidence cloud

PRODUCT MATURITY: VALIDATED over ocean and vegetated land, PROVISIONAL over non-vegetated land

Maturity designation to be upgraded after automated thresholding in place

Level 2 Standard Products / Ancillary Products

Level 2 standard products

- Level 2TC stereo
- Level 2TC cloud classifiers
- Level 2TC top-of-atmosphere albedo
- Level 2AS aerosol
- Level 2AS land surface
- Level 2AS ocean surface (not yet available)

Level 2 processing uses multiple cameras simultaneously

- Angular radiance signatures
- Geometric parallax

Ancillary products

Ancillary Radiometric Product

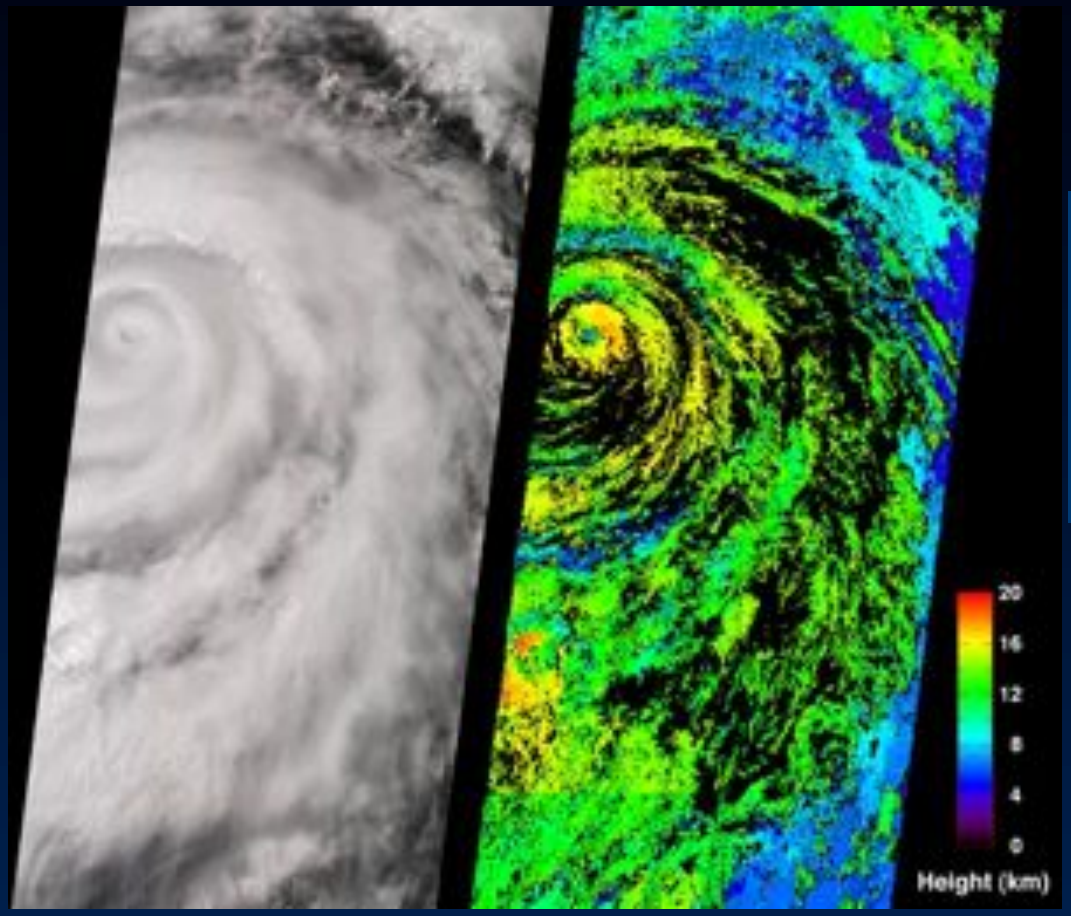
contains extrasolar irradiances at MISR standard wavelengths

Ancillary Geographic Product

contains latitudes, longitudes, elevations, scene classifiers for each 1.1-km pixel on the Space Oblique Mercator grid

L2 TOA/Cloud Stereo Product (MIS04)

Retrieved cloud heights and cloud-tracked winds



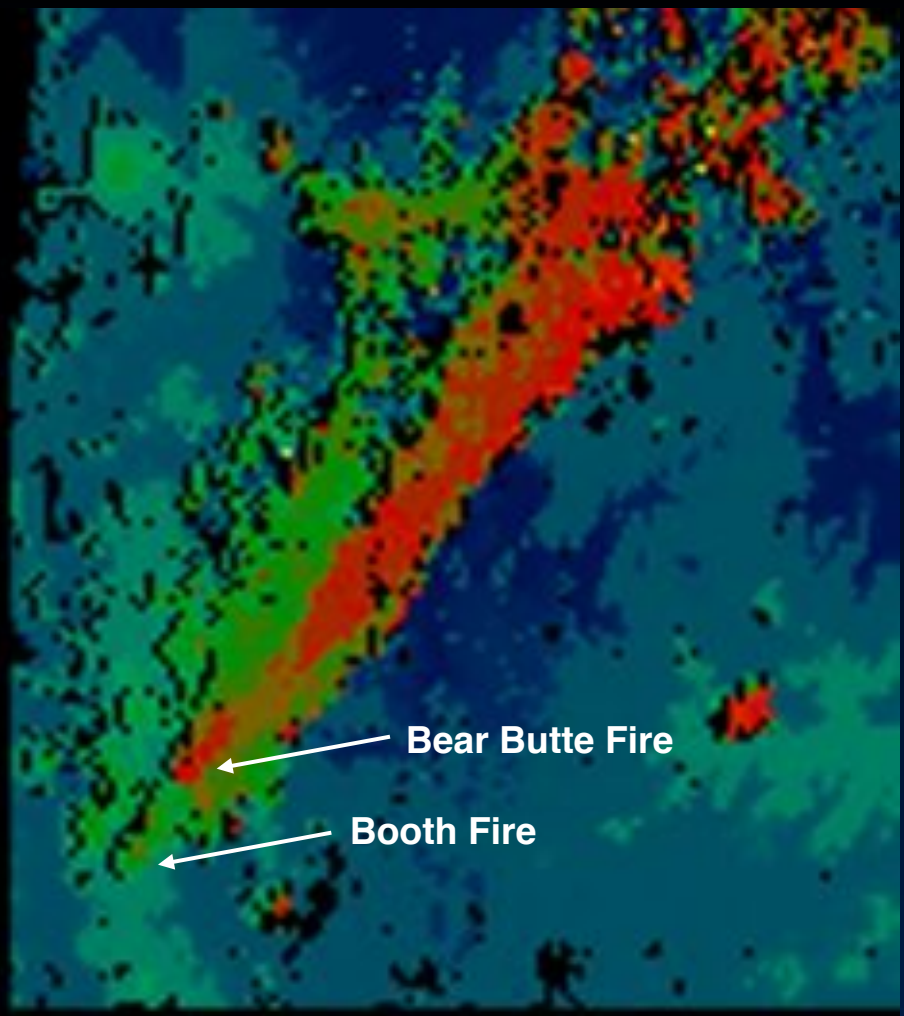
PRODUCT MATURITY: VALIDATED

- Purely geometric retrievals of height
- Both "zero wind" and wind-adjusted height fields provided

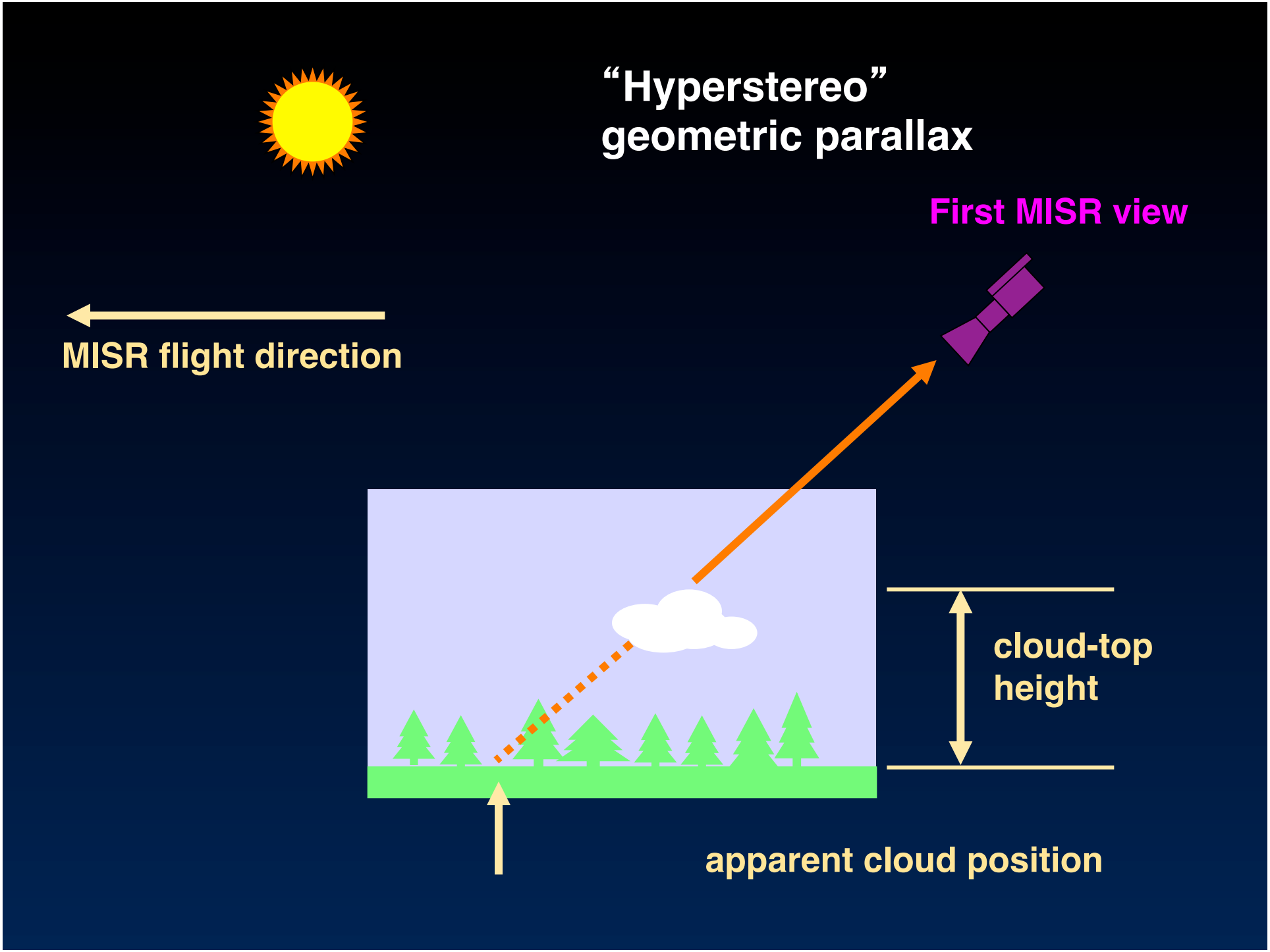
Hurricane Juliette
26 September 2001

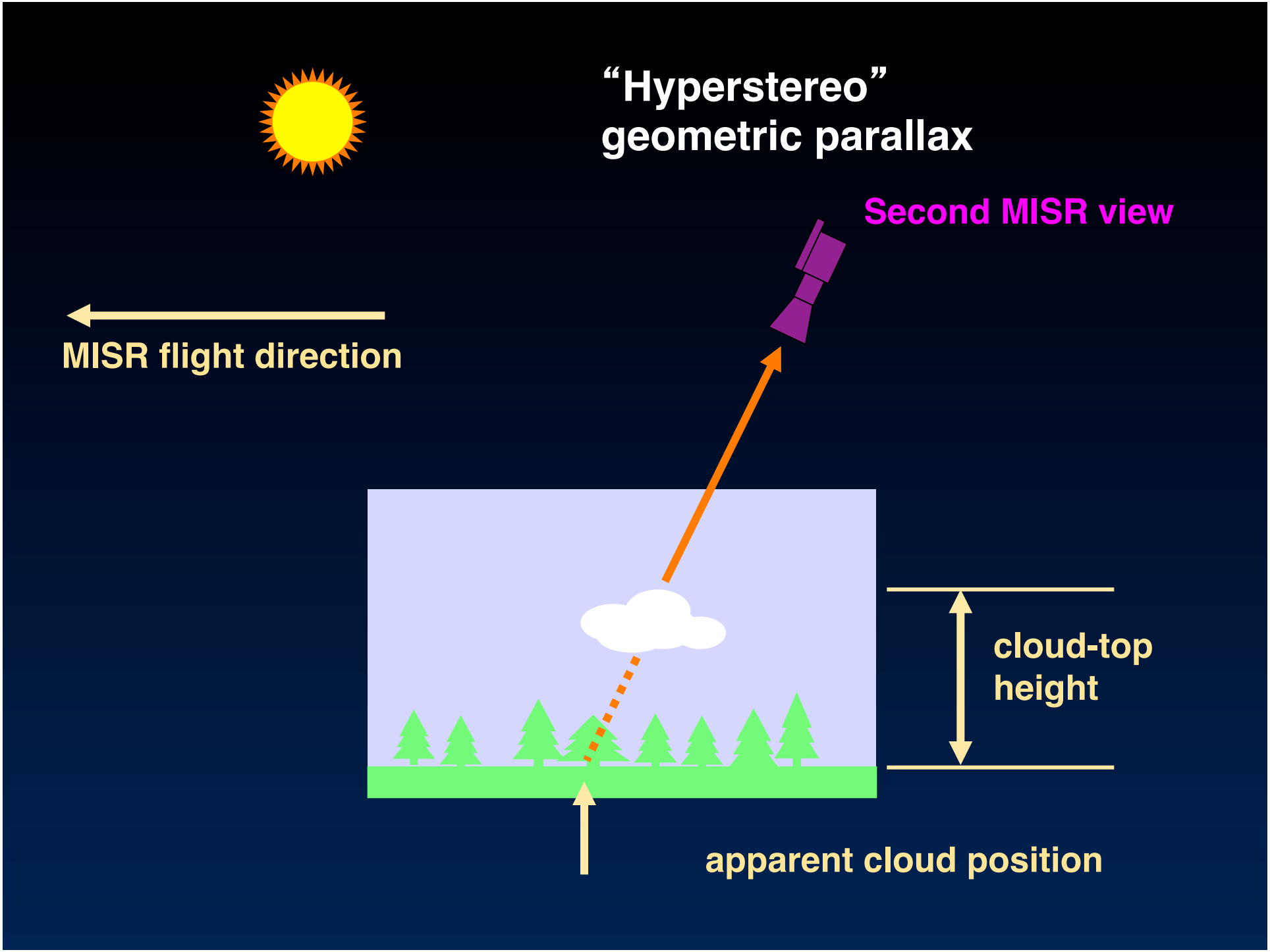
Plume-height mapping using stereo

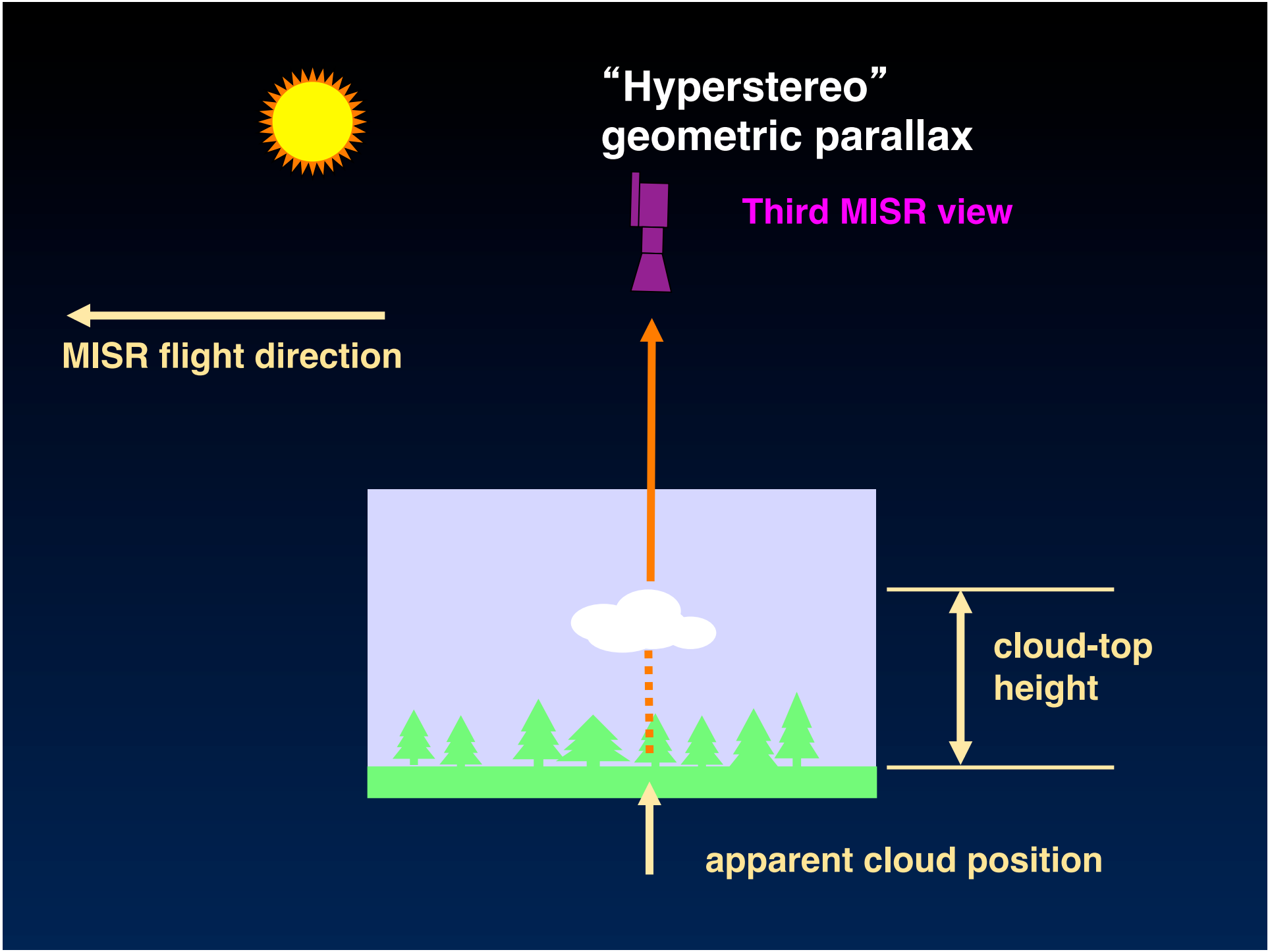
Nadir image



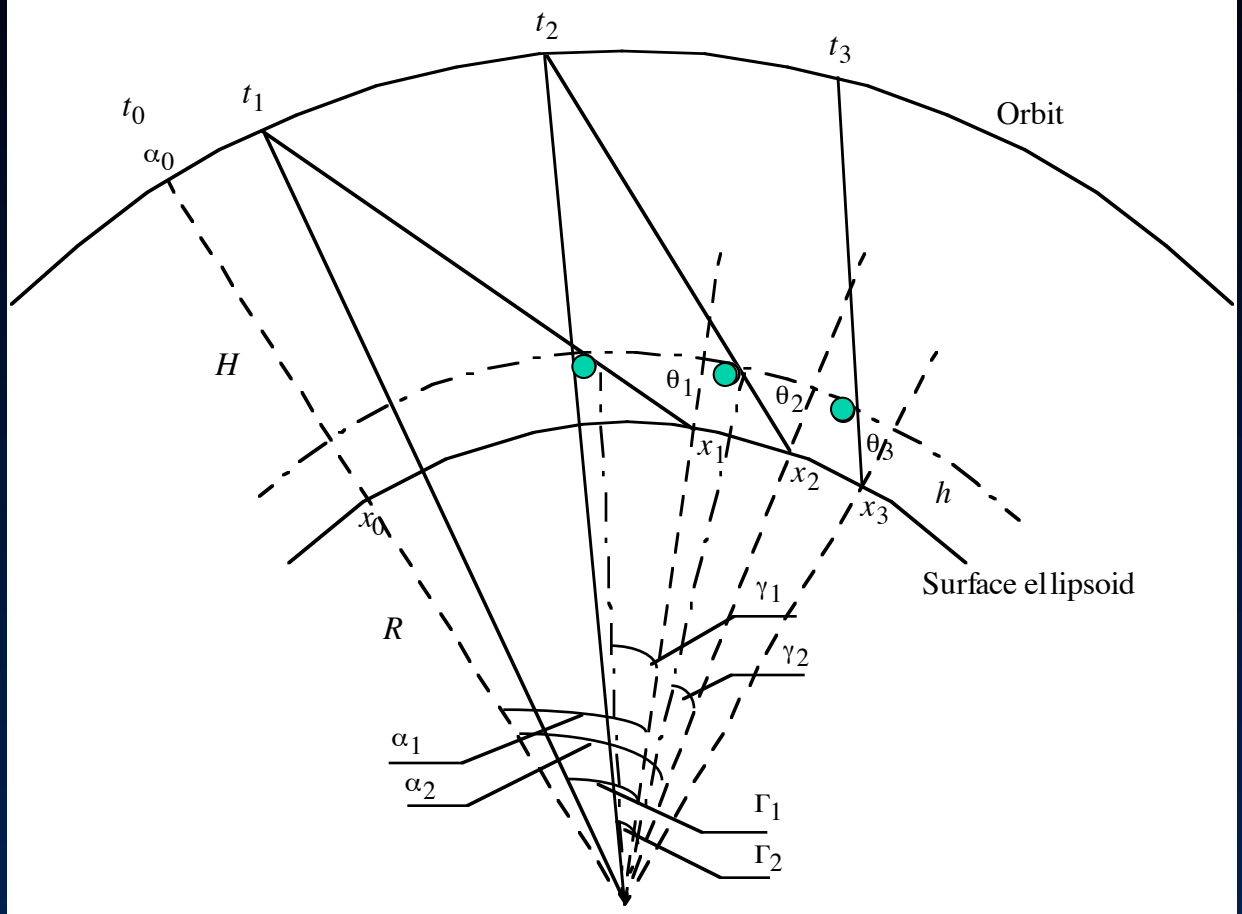
B&B Complex Fire, Oregon
4 September 2003


"Hyperstereo"
geometric parallax
First MISR view
MISR flight direction
cloud-top
height
apparent cloud position


"Hyperstereo"
geometric parallax
Second MISR view
MISR flight direction
cloud-top
height
apparent cloud position


"Hyperstereo"
geometric parallax
Third MISR view
MISR flight direction
cloud-top
height
apparent cloud position

Motion tracking



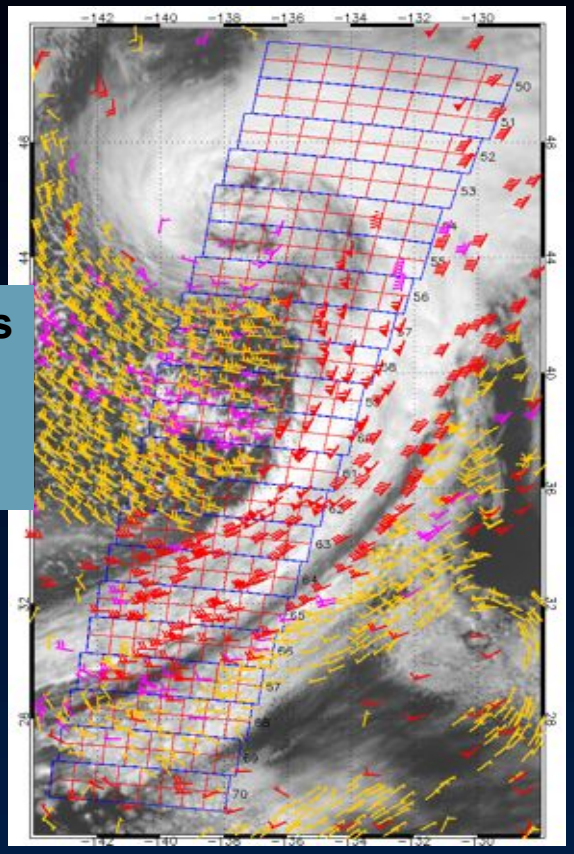
Height and horizontal motion separation requires 3 look angles

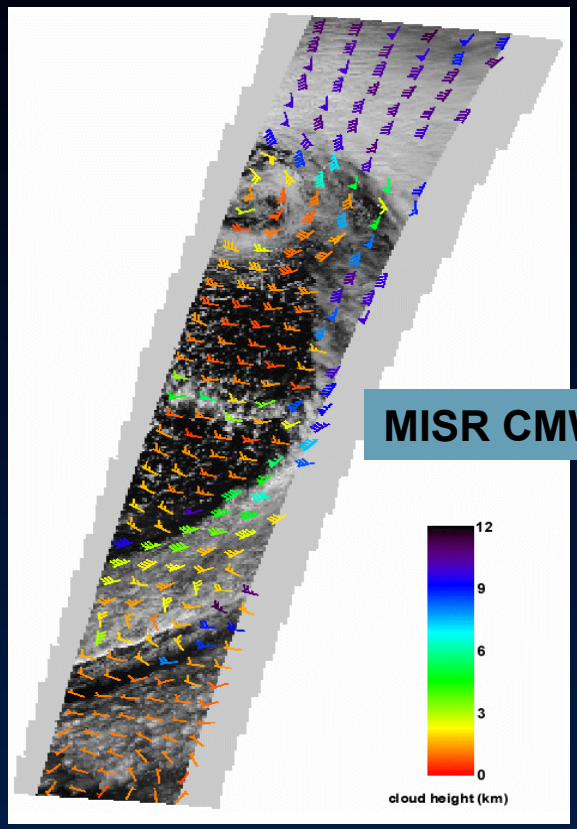
Observation from satellite altitude is required: Earth curvature overcomes equation degeneracy

Height-resolved cloud-motion winds

Extratropical cyclone

GOES CMWs
low
middle
high

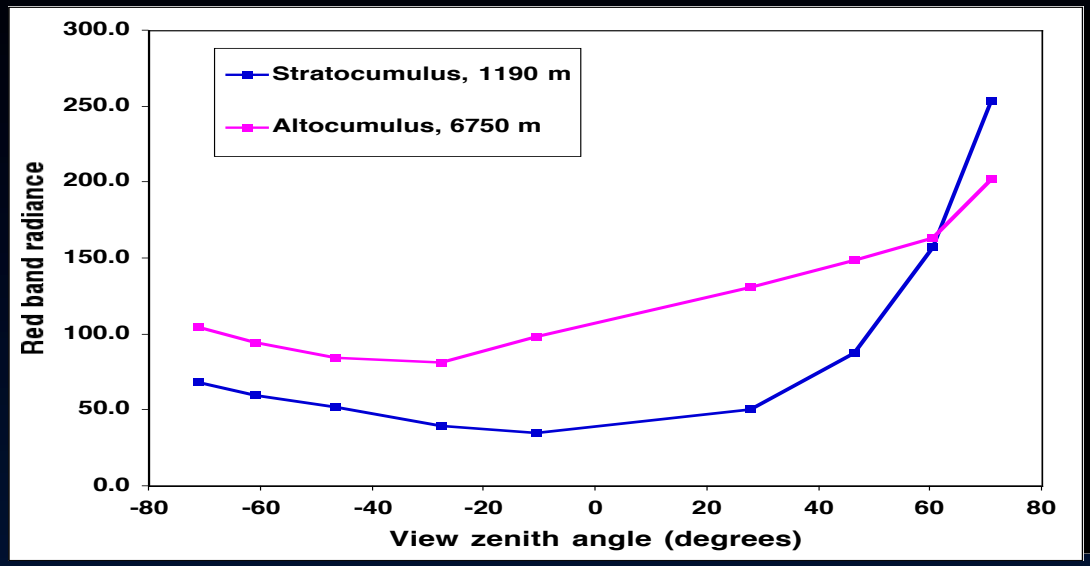


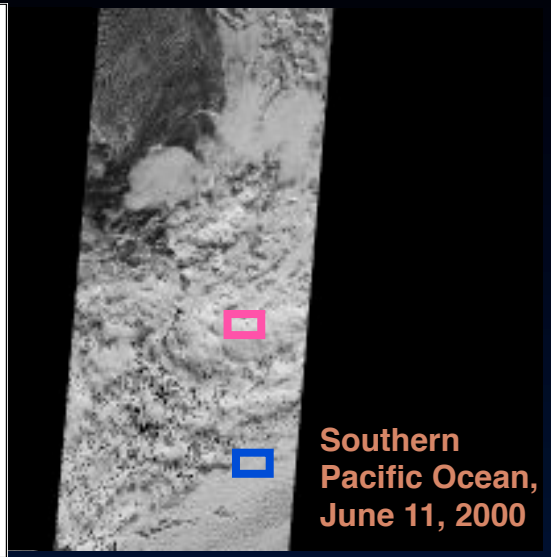


Horvath and Davies (2001; JAOT 18)

L2 TOA/Cloud Albedo Product (MIS04)

Cloud-top-projected TOA albedo and bidirectional reflectance

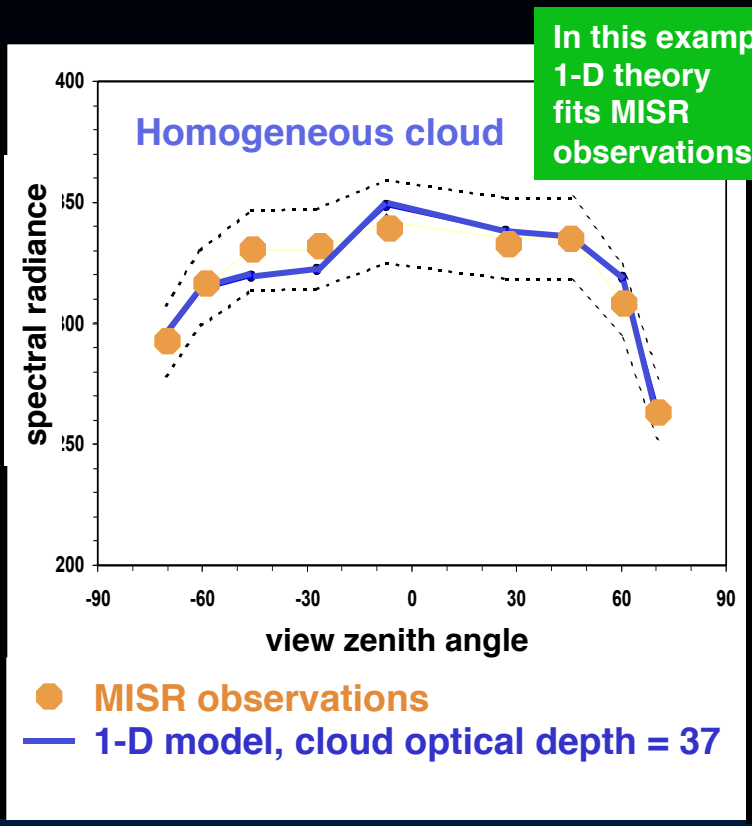


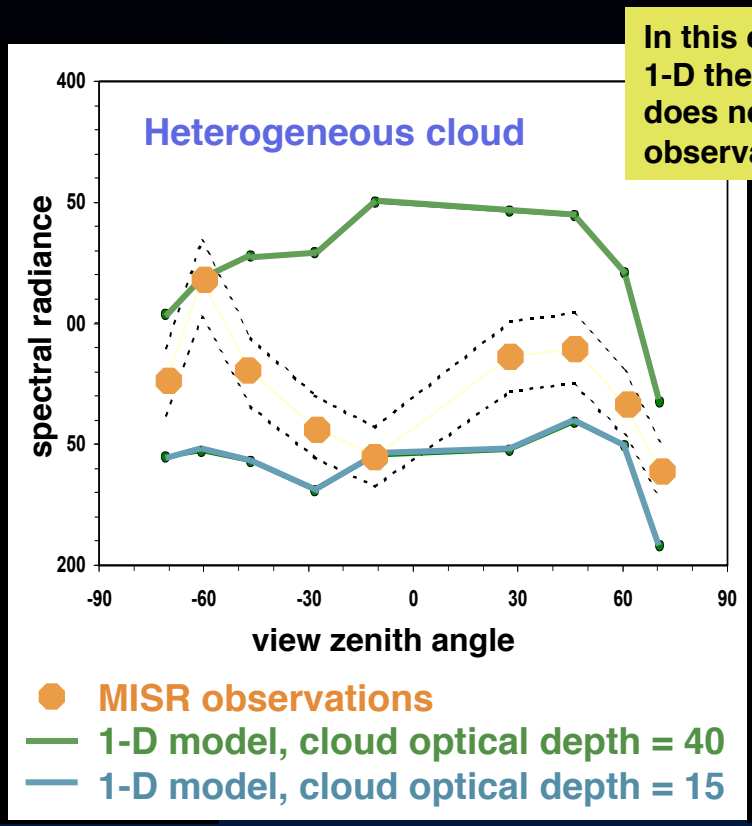


PRODUCT MATURITY: VALIDATED

- Contains "feature-referenced" top-of-atmosphere bidirectional reflectances
- Includes three types of TOA albedos in product:
  - -- local: 2.2 km sampling, for use with scene classification
  - -- restrictive: 35.2 km sampling, characterizes reflection within 35.2 km area
  - -- expansive: 35.2 km sampling, integrates reflection over large spatial area as if observed by a pyranometer above the atmosphere
- Regressions against CERES being used to facilitate narrow-to-broadband conversion

Exploring the effect of 3-dimensional structure on retrieved cloud properties

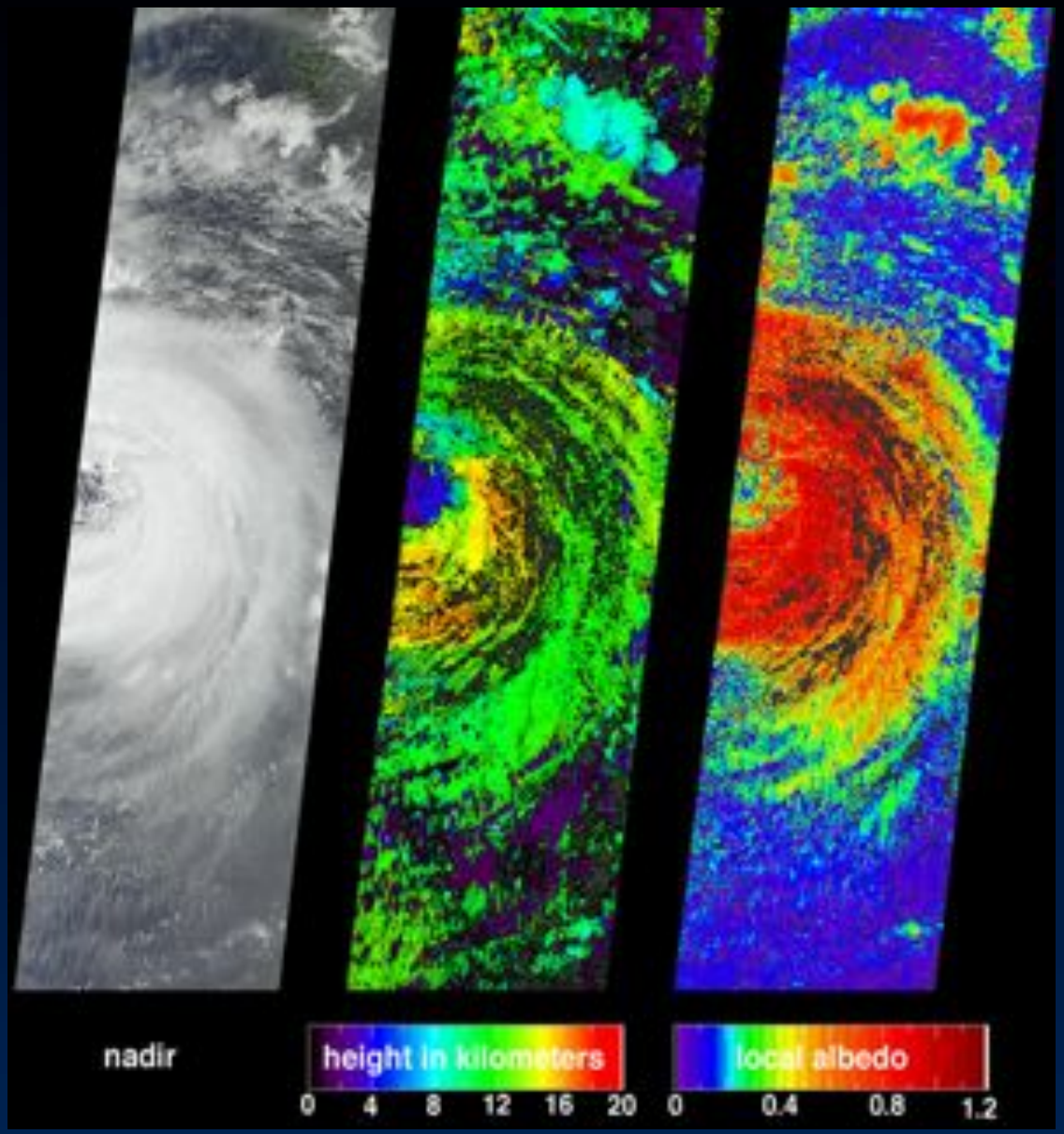




MISR data make it possible to identify when conventional (1-D) retrievals of cloud properties are valid. At 1-km resolution this occurs < 20% of the time.

Horvath and Davies (2004; GRL 31)

Example stereo and local albedo cloud products



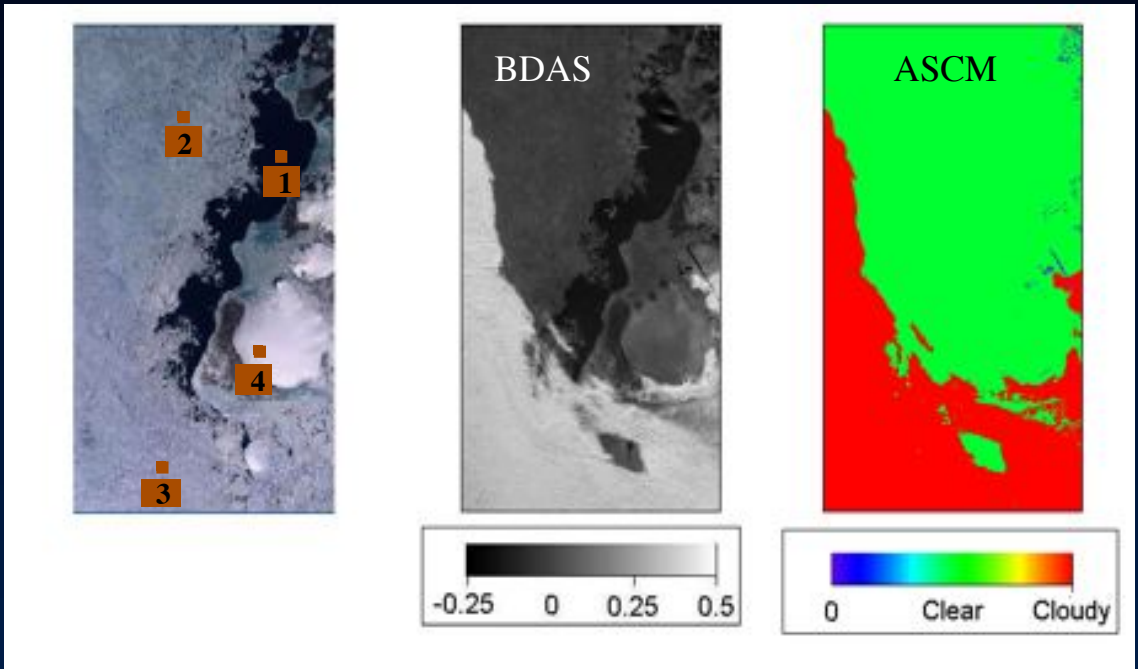
Typhoon Sinlaku
September 5, 2002

L2 TOA/Cloud Classifiers Product (MIS04)

Angular signature cloud mask and height-binned cloud fractions

PRODUCT MATURITY: PROVISIONAL

- Angular signature readily distinguishes clouds and low-lying polar fogs from snow and ice



Nadir image

Band-differenced angular signature

Angular signature cloud mask

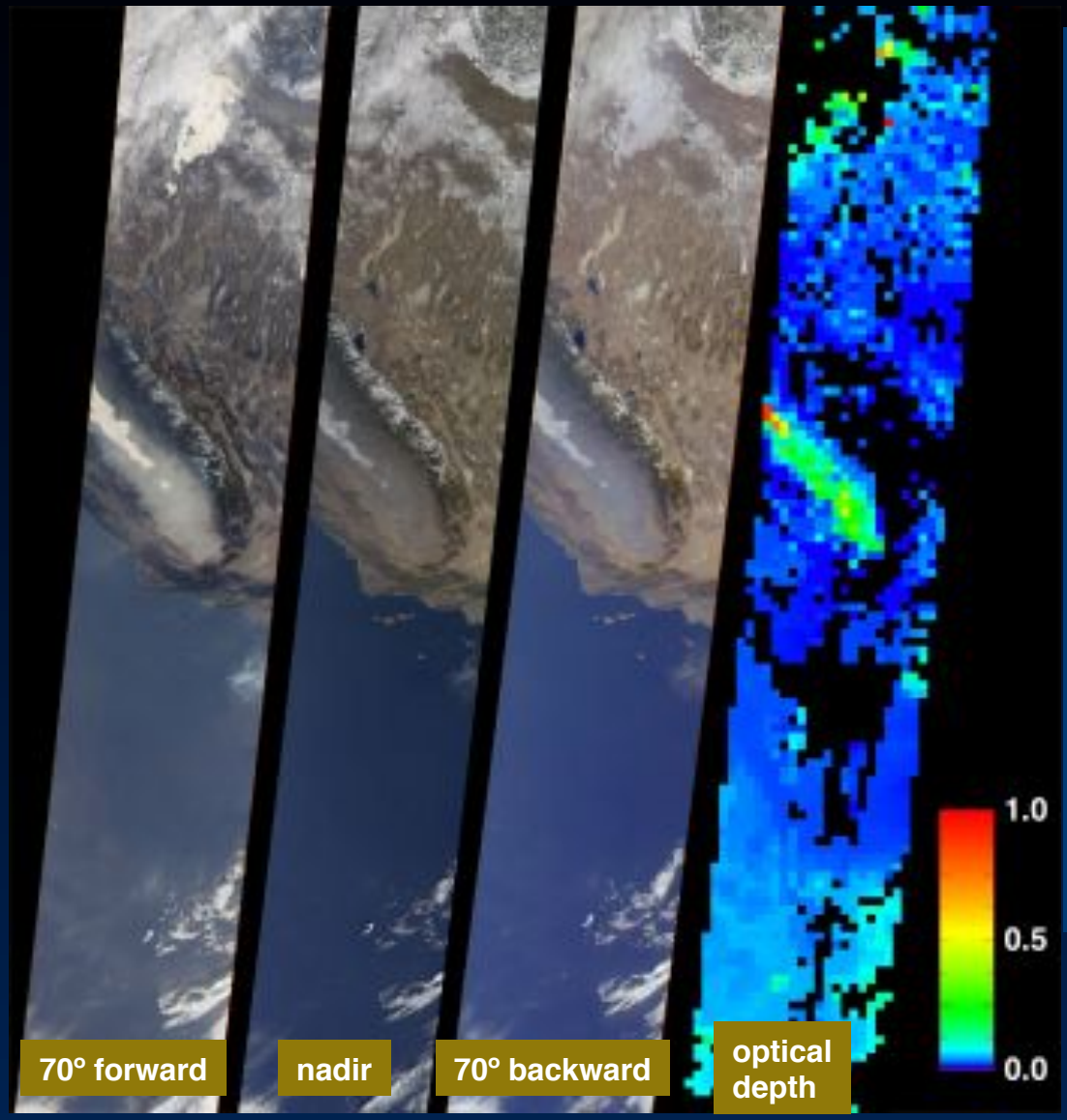
Data over the Arctic Ocean north of Russia, 3 July 2001, showing a mix of scene types:
1--open water
2--sea ice
3--cloud
4--snow-covered land (Komsomolets Island)

The cloud is difficult to see at nadir since it is at low altitude (MISR stereoscopic heights ~ 600 m), and optically thin.

Di Girolamo and Wilson (2003; IEEE TGARS 41)

L2 Aerosol/Surface Product (MIS05)

Aerosol parameters

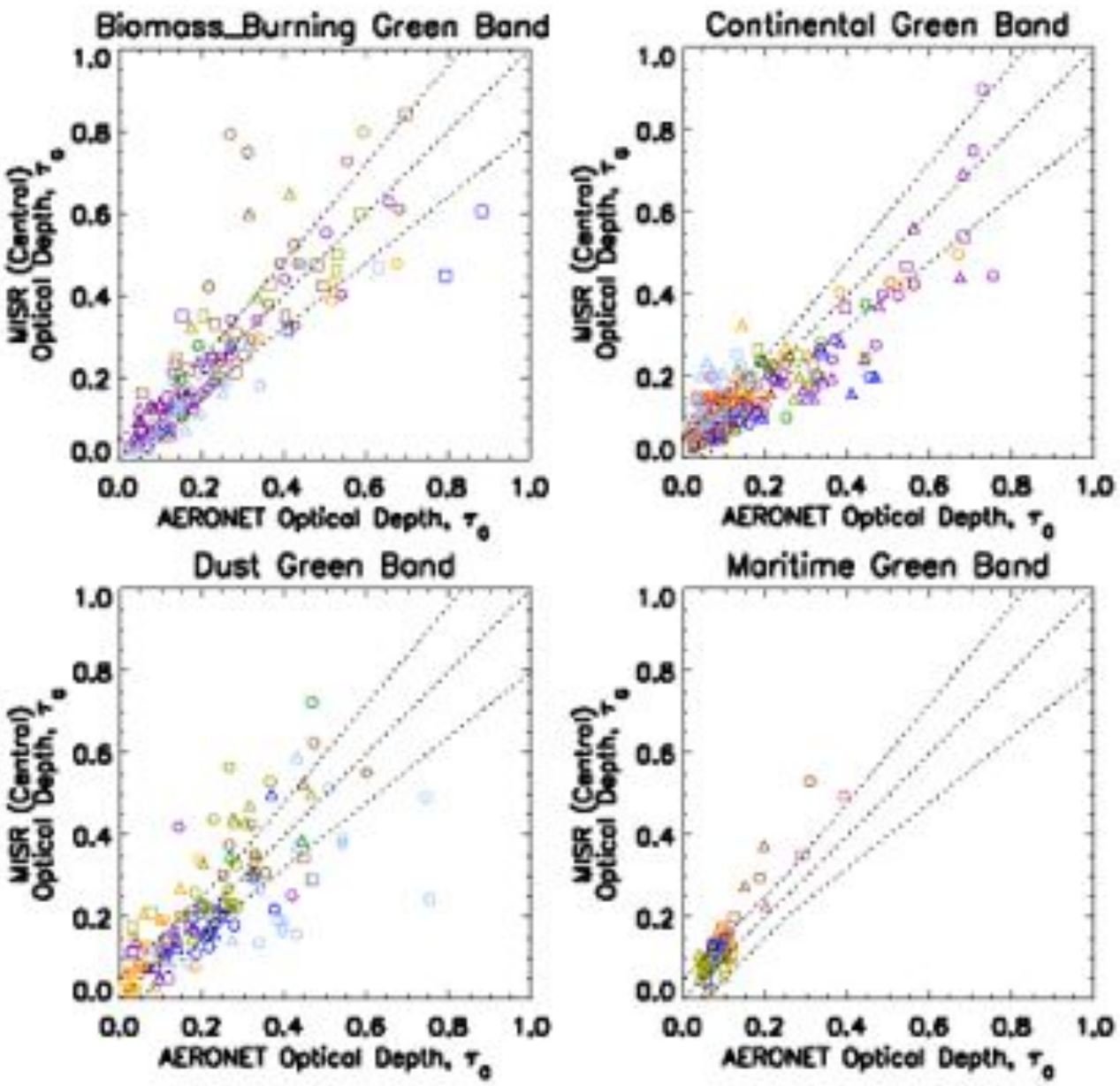


Martonchik et al. (2002; IEEE TGARS 40)

PRODUCT MATURITY:
VALIDATED (optical depth only)
BETA (particle properties)

- Different algorithms used over land and water
- Validation and quality assessment of optical depth performed
- Detailed work on aerosol particle properties under way
  - --Angstrom exponent
  - --Size binned fractions
  - --SSA
  - --Sphericity
- Particle property models to be upgraded (e.g., new dust optical properties/shapes)

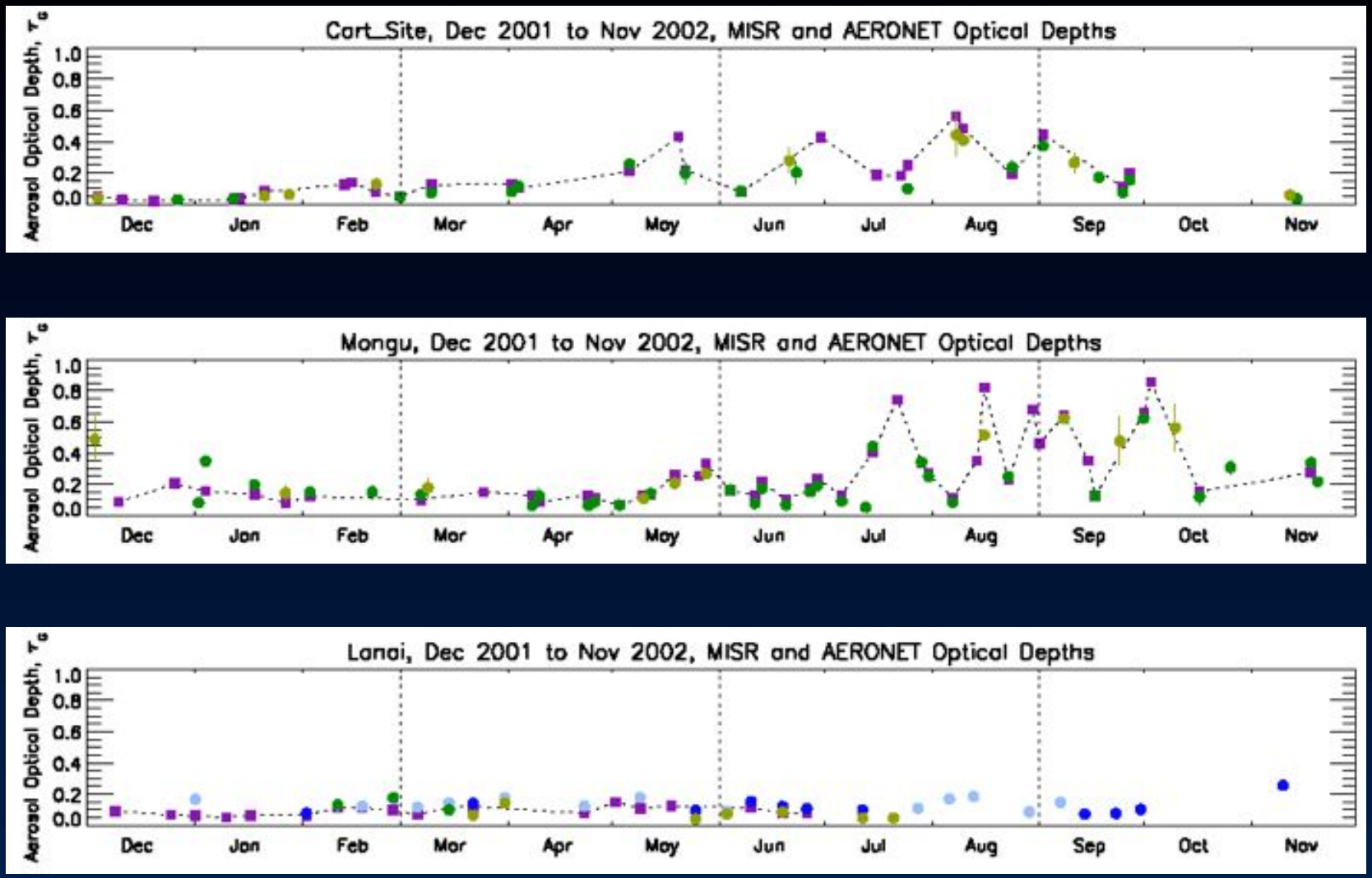
Southern California and Southwestern Nevada
January 3, 2001



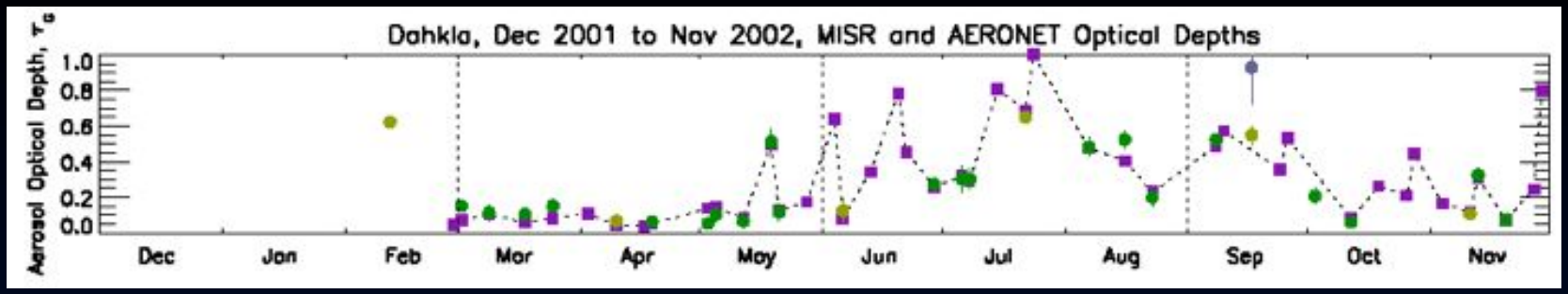
Optical depth validation

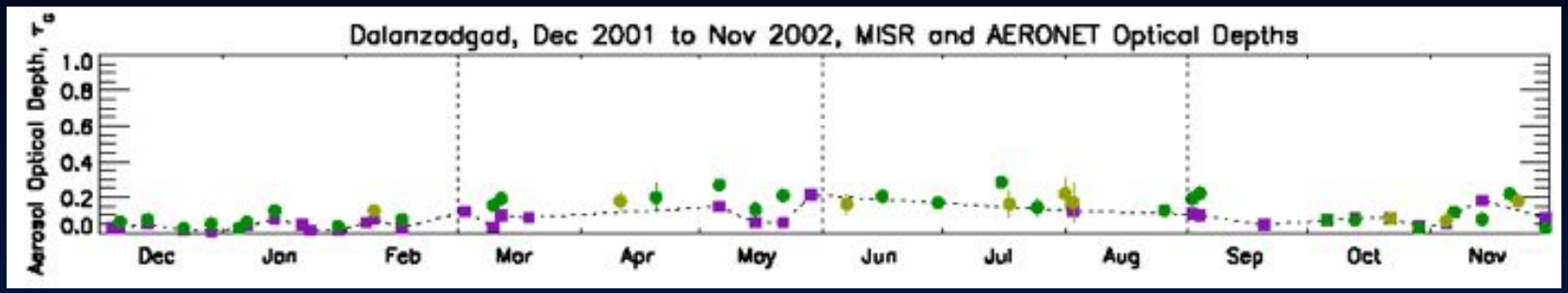
Kahn et al. (2004; JGR, submitted)

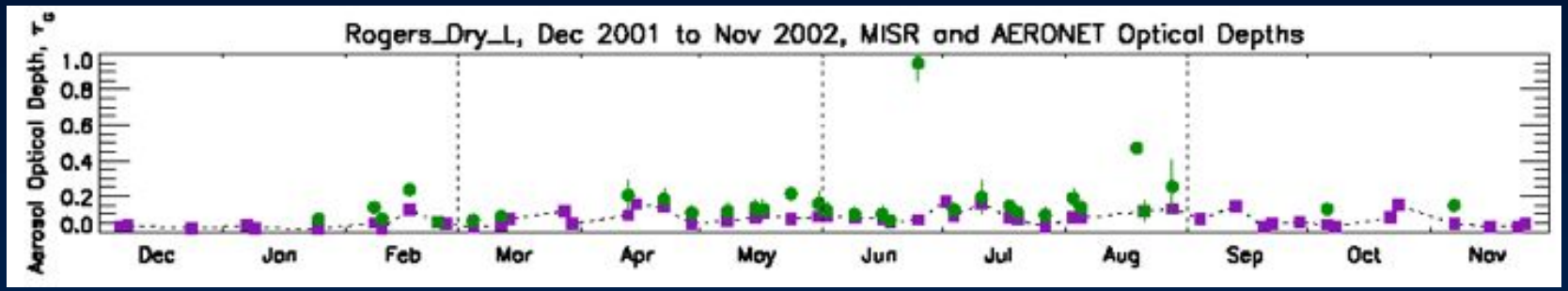
MISR-AERONET time series, dark surfaces



MISR-AERONET time series, bright surfaces







AERONET MISR Land MISR Water

L2 Aerosol/Surface Product (MIS05)

Surface parameters

Nadir NIR spectral top-of-atmosphere composite

Multi-angle top-of-atmosphere composite

forest

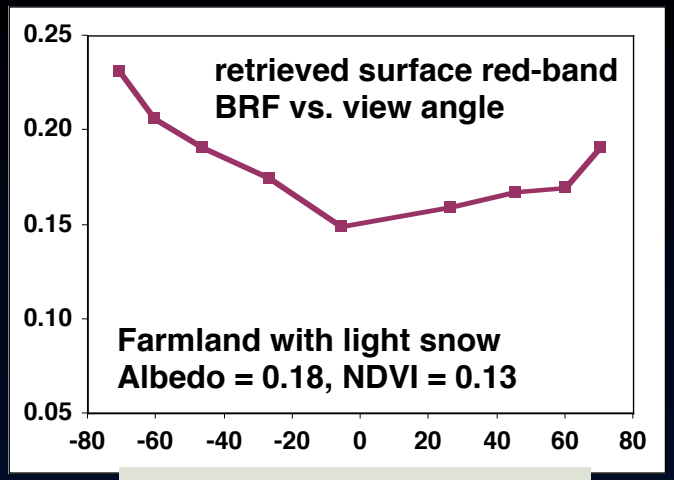
farmland

Manitoba and Saskatchewan, April 17, 2001

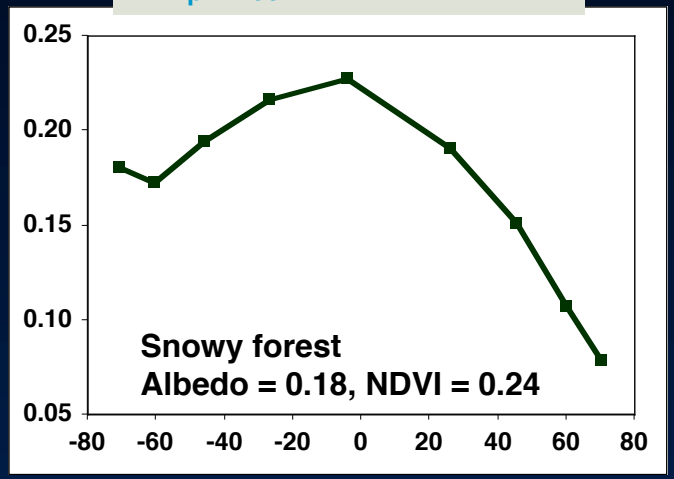
PRODUCT MATURITY: PROVISIONAL

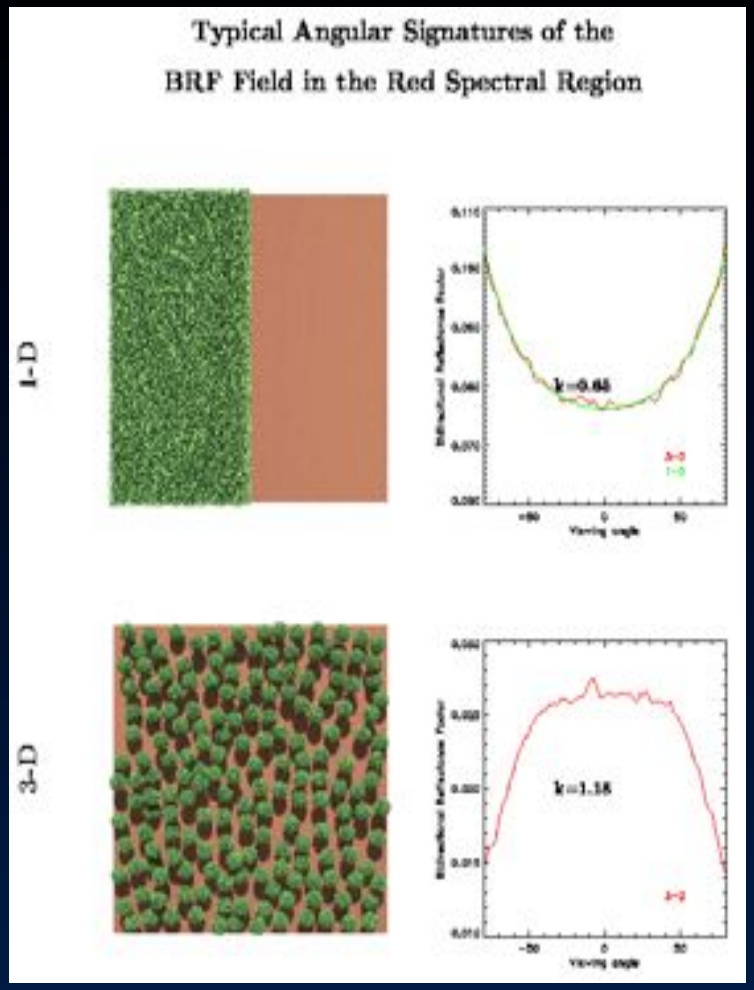
- Includes radiometric surface parameters (directional reflectances, albedos) as well as vegetation-related quantities (albedo-based surface NDVI, LAI, FPAR)

Bidirectional reflectances of surface vegetation



Manitoba and Saskatchewan,
17 April 2001



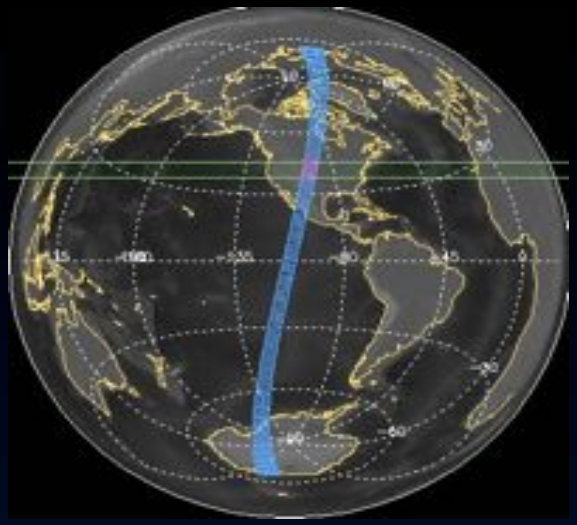


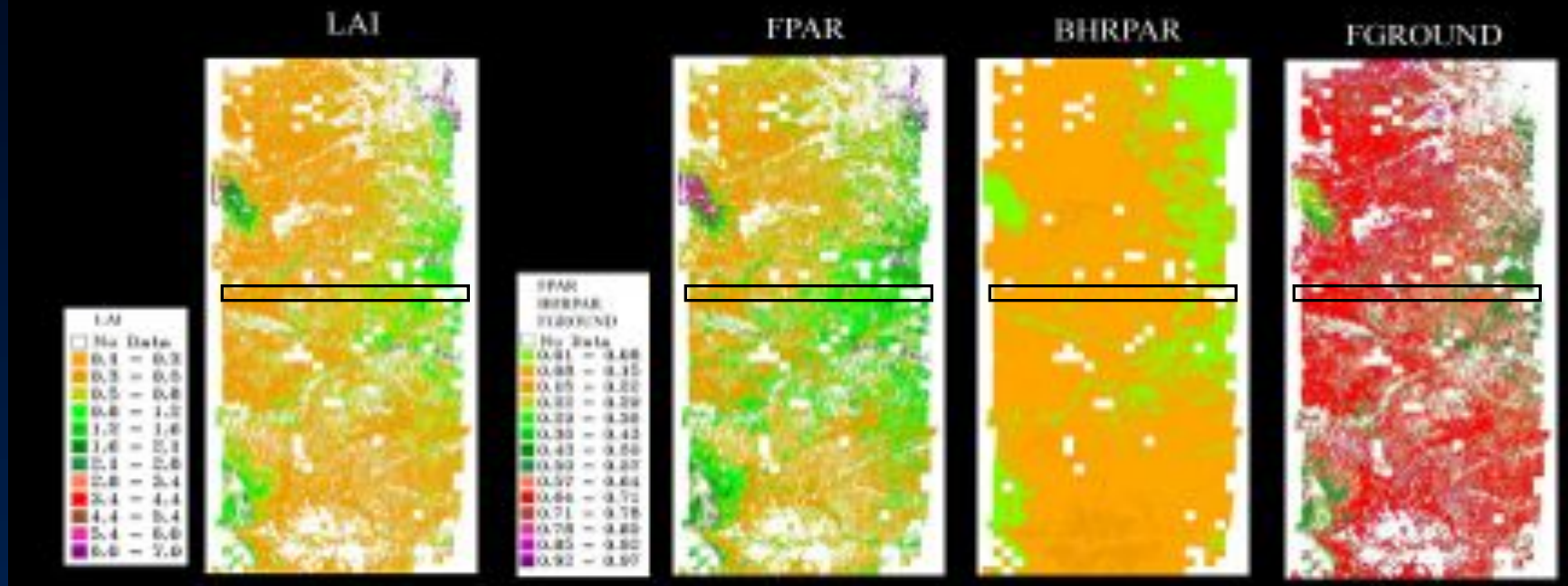
Pinty et al. (2002; IEEE TGARS 40)

MISR characterizes the heterogeneity of land surface vegetation. This is important for ecological models, and for partitioning radiation between the canopy and the ground.

Interaction of sunlight with vegetation and the ground

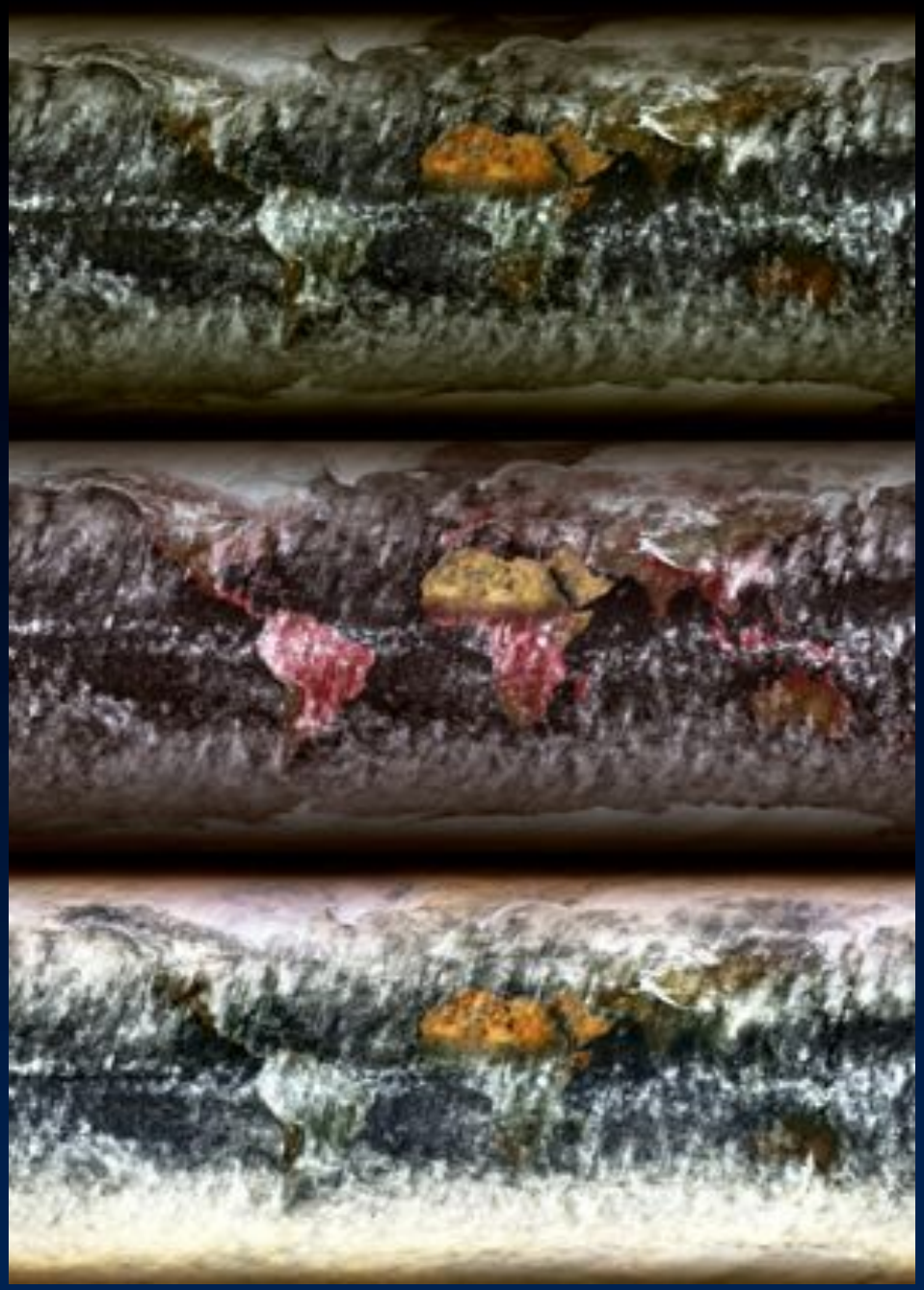
15 August 2003
South Dakota, Nebraska, Colorado





FGROUND = 1 - BHRPAR - FPAR

Y. Knyazikhin, Boston U.



L3 Gridded Radiances (MIS06)

Means, variances, and covariances

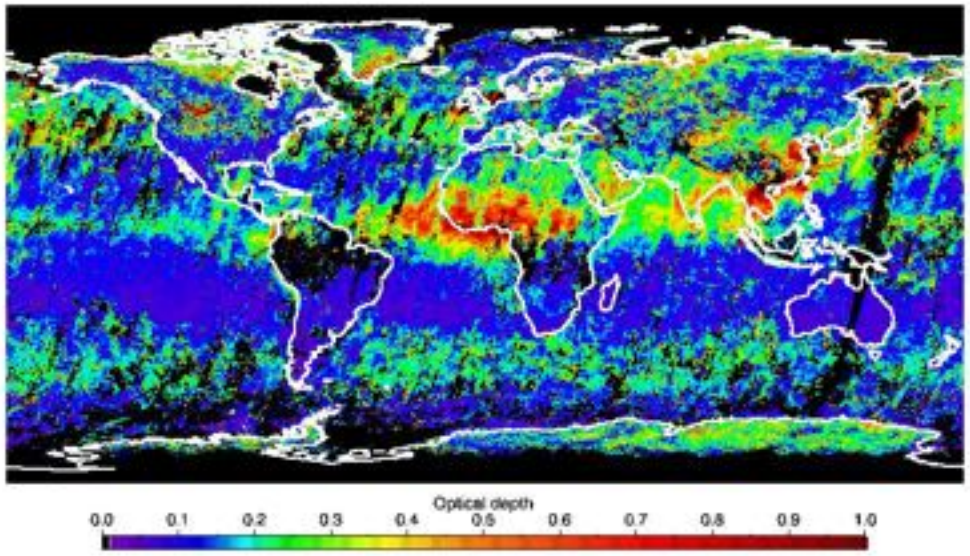
Nadir red, green, blue

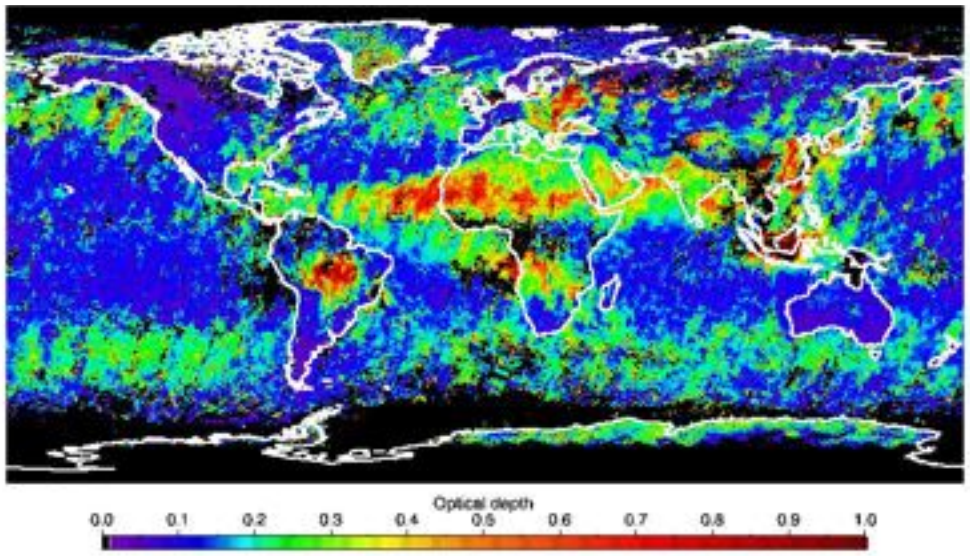
PRODUCT MATURITY: VALIDATED

Nadir near-infrared, red, green

March 2002

70° forward: red, green, blue (N. hemisphere)
70° backward: red, green, blue (S. hemisphere)





L3 Gridded Aerosol (MIS08)

Optical depths, particle properties

March 2002

PRODUCT MATURITY: VALIDATED

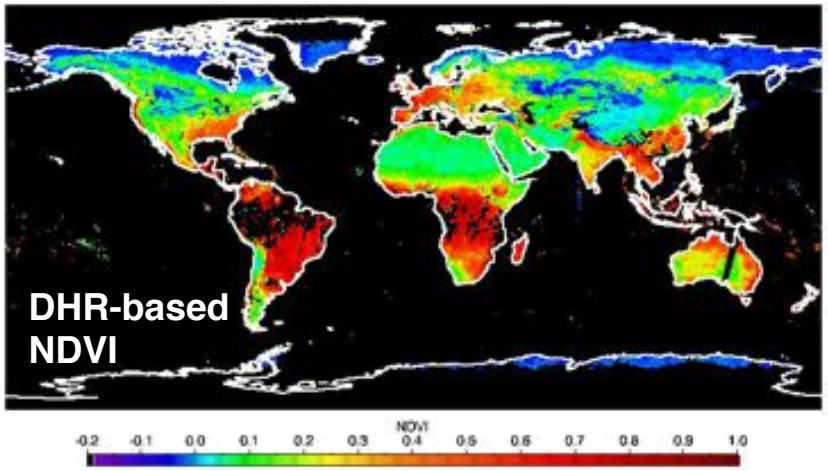
- Optical depth means and counts at present

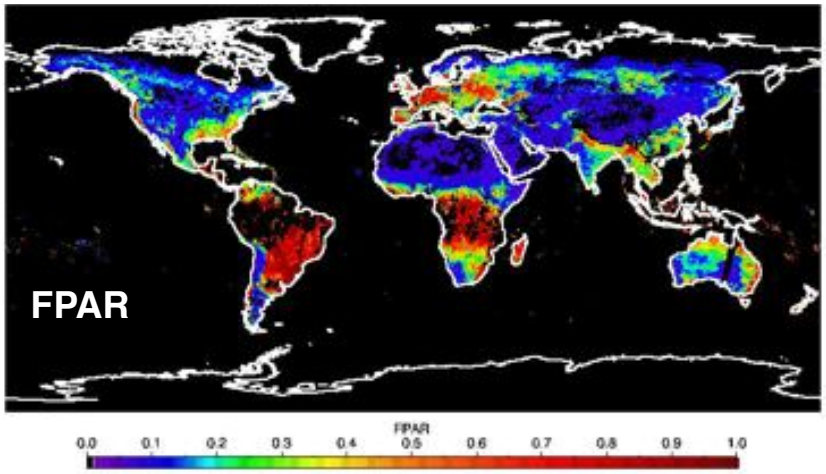
September 2002

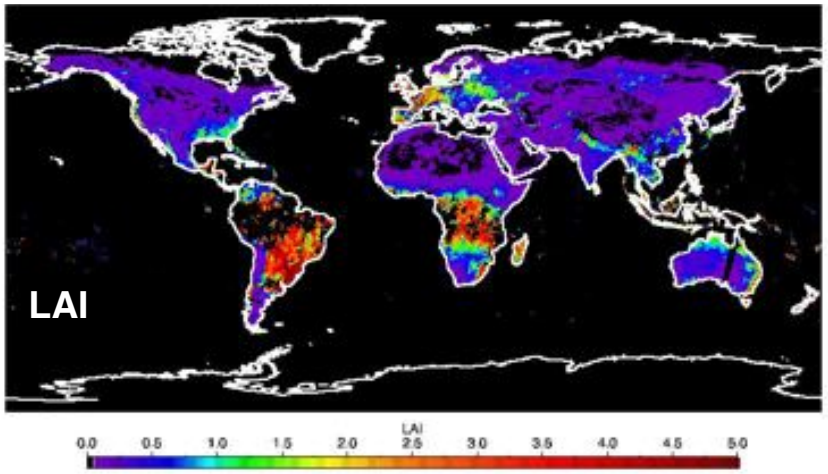
L3 Gridded Surface (MIS09)

Radiative and biogeophysical parameters

PRODUCT MATURITY: PROVISIONAL







Additional products you might need

Ancillary Radiometric Product

--contains extrasolar irradiances, standard wavelengths

--however, key information is being added to the L1B2 products to enable conversion from radiance to BRF

Ancillary Geographic Product

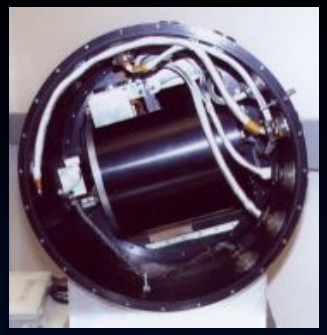
--contains latitudes, longitudes, elevations, scene classifiers for each 1.1-km pixel on the Space Oblique Mercator grid

Aerosol Climatology Product

--Aerosol Physical and Optical Properties (APOP) contains characteristics of the component particles used in the aerosol retrievals

--Mixture file contains characteristics of the particle mixtures used

AirMISR



Flies in nose of NASA ER-2

Covers MISR's nine angles

Uses gimballed MISR prototype camera

27.5 m georectified spatial resolution

9 x 11 km area covered at all angles

Data available at LaRC DAAC

46° images near Howland, ME 28 August 2003

Where to get help and information:

LaRC DAAC User Services
larc@eos.nasa.gov

Langley Atmospheric Sciences Data Center DAAC
http://eosweb.larc.nasa.gov

MISR home page
http://www-misr.jpl.nasa.gov

"Special Section on MISR" in July 2002
IEEE Transactions on Geoscience and Remote Sensing
17 papers about the instrument, data products, calibration, retrieval methods, and results

We welcome your feedback!
suggestions@mail-misr.jpl.nasa.gov